PATENT COOPERATION TREATY

PCT

REC'D 07 MAY 2001
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INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
P9797PCOO/LN/ar		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/DK00/00162	31/03/2000	31/03/1999
International Patent Classification (IPC) or national classification and IPC H02K1/12		
Applicant BONUS ENERGY A/S et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 14 sheets.

3. This report contains indications relating to the following items:

   - I ☒ Basis of the report
   - II ☐ Priority
   - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - IV ☐ Lack of unity of invention
   - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   - VI ☐ Certain documents cited
   - VII ☐ Certain defects in the international application
   - VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
02/10/2000	03.05.01
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Torlai, P Telephone No. +49 89 2399 2293

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No. PCT/DK00/00162

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:
Description, pages:

2,5,6	as originally filed			
1,3,3A,4,4A,7-9	as received on	06/04/2001	with letter of	03/04/2001

Claims, No.:

1-11	as received on	06/04/2001	with letter of	03/04/2001

Drawings, sheets:

1/7-3/7	as originally filed			
4/7-7/7	as received on	06/04/2001	with letter of	03/04/2001

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

   ☐ the description, pages:

   ☐ the claims, Nos.:

   ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-11
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-11
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-11
	No:	Claims	

2. Citations and explanations
   see separate sheet

Re Item V

Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

Novelty:
Document US-A-4866321 (D1), which is considered to represent the most relevant state of the art, describes a generator for a windmill of the kind driven directly by the rotor of the windmill without any gearbox installed between the rotor and the generator (see column 1, lines 25-33) , wherein at least the stator of the generator is made with at least two modules which may be mounted and dismantled independently of each other one or more at the time (see pictures 2 and 5, column 3, line 63 to column 4, line 29). From the fact that the generator is used in a windmill to be installed in the open air it is assumed that the generator according to D1 must be protected by means of a tight enclosure enclosing the whole generator.

The subject-matter of the new independent Claim differs from the generator described in D1 in the following features:
each module is individually contained in an enclosure with a degree of sealing substantially corresponding to the degree of sealing which is desired in the finished generator , and
a given number of juxtaposed enclosures abutting on each other form a closed ring of stator modules.
For this reason subject-matter of Claim 1 is new in respect of prior art as defined in the regulations (Rule 64(1)-(3) PCT) .

Inventive step

According to the new claim 1 the modules are individually enclosed in tight enclosures

The problem to be solved by the claimed invention is
described on page 3A, lines 6-11.
None of the documents of the international search report discloses a generator with the characterising features of the new claim 1.

The teaching of said documents even if combined together (supposed a skilled man would do it) would not lead to the solution proposed in claim 1.

For these reasons the solution is not considered to be obvious.

Claims 2-11 are dependent claims of claim 1 so that also the subject matter of these claims is considered as involving an inventive step.

Industrial application
The claimed invention is considered as susceptible of industrial application.

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V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-11
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-11
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-11
	No:	Claims	

2. Citations and explanations
   see separate sheet

Re Item V

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Novelty:

Document US-A-4866321 (D1), which is considered to represent the most relevant state of the art, describes a generator for a windmill of the kind driven directly by the rotor of the windmill without any gearbox installed between the rotor and the generator (see column 1, lines 25-33) , wherein at least the stator of the generator is made with at least two modules which may be mounted and dismantled independently of each other one or more at the time (see pictures 2 and 5, column 3, line 63 to column 4, line 29). From the fact that the generator is used in a windmill to be installed in the open air it is assumed that the generator according to D1 must be protected by means of a tight enclosure enclosing the whole generator.

The subject-matter of the new independent Claim differs from the generator described in D1 in the following features:

each module is individually contained in an enclosure with a degree of sealing substantially corresponding to the degree of sealing which is desired in the finished generator , and

a given number of juxtaposed enclosures abutting on each other form a closed ring of stator modules.

For this reason subject-matter of Claim 1 is new in respect of prior art as defined in the regulations (Rule 64(1)-(3) PCT) .

Inventive step

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The problem to be solved by the claimed invention is
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None of the documents of the international search report discloses a generator with the characterising features of the new claim 1.

The teaching of said documents even if combined together (supposed a skilled man would do it) would not lead to the solution proposed in claim 1.

For these reasons the solution is not considered to be obvious.

Claims 2-11 are dependent claims of claim 1 so that also the subject matter of these claims is considered as involving an inventive step.

Industrial application

The claimed invention is considered as susceptible of industrial application.

GENERATOR FOR A WINDMILL, STATOR MODULE FOR USE IN SUCH A GENERATOR AND USE OF SUCH A GENERATOR

Background of the invention

The present invention relates to a generator for a windmill of the kind driven directly by the rotor of the windmill without any gearbox installed between the rotor and the generator wherein at least the stator of the generator is made of modules of which one or more stator modules can be dismantled independently without having to dismantle the entire winding.

It is known that it is necessary to insert a speed increasing gearbox between the rotor and the generator of a windmill. The rotational speed is of the magnitude 20 rpm for large windmills while a normal 4-pole generator has a synchronous speed of rotation of 1500 rpm. A suitable speed increasing gearbox will thus have a gear ratio of 1:75.

It is known that the speed increasing main gearbox of a windmill constitutes a substantial part of the cost price, and besides that it is a relatively vulnerable main component. In many cases, by possible damages, it will be necessary to dismantle the gearbox for repair. In consideration of the gearbox for a windmill in the 2 MW class having a weight of up to 15 tons and being mounted in a machine disposed on a tower with a height of 60-100 m it is obvious that such a replacement may be very costly.

The risk of incurring considerable expenses by a possible replacement is multiplied if large windmills are erected at sea. Handling of weights of 15 tons or more in 60-100 m height may only be performed with very large float cranes or very large mobile cranes placed on large barges. Working with this kind of equipment at the open sea can only be done under good weather conditions. Therefore, there may be periods of several months during the winter where it is not possible to replace a damaged gearbox.

The generator itself is also a heavy main component, typically with a weight of 5 tons by 2 MW rated output. As with the gearbox it cannot be avoided that there will be a

pact machine construction. In addition, here it will be necessary to dismantle the whole rotor by eventual dismantling of the generator.

From WO-A1-98/20595 a stator assembled from modules is known, where the stator windings on each module can be premade, and the entire winding can thereafter be assembled on site. This construction makes transport to the site of erection easier. This construction requires a stator housing as such, and this stator housing requires a diameter which is substantially larger than the air gap diameter.

From US-A-4,594,552 another generator having a stator built from modules is known, which modules can be dismantled without the entire winding being dismantled. This construction, however, also requires a stator housing as such, and that the stator housing has a diameter substantially larger than the air gap diameter.

There is known an embodiment of a directly driven generator, US patent 5,844,341, where the stator of the generator is made with modules which largely constitute individual polar pairs and which are disposed on support arms outside the poles. The advantage of this construction is that a damaged part of the generator may be replaced without taking down the whole generator. The drawback by this configuration is, however, that the electromechanical properties in this form of modular construction with single polar pairs separated by air gaps may be disadvantageous, and that possible dismantling of a single stator module can involve that the whole generator has to be opened in situ implying risk of humidity, dirt etc., and that it may be cumbersome if the stator module has to be taken out in a disadvantageous direction.

Another design of a directly driven generator is known, US patent 4,866,321, where an axial generator has a stator designed with modules each containing a single pole winded around a coil and installed in an arrangement where the coil may be drawn radially out from the stator. The advantage of this construction is, as with the previous, that a damaged pole in the generator may be replaced without the whole generator to be taken down. As a consequence of the mechanical construction it is likely that the electromechanical properties will be better than in the above arrangement. The draw-

back is, however, that possible dismantling of a single stator module can involve that the whole generator has to be opened in situ implying risk of humidity, dirt etc., and that it may be cumbersome if the stator module has to be taken out in a disadvantageous direction.

It is the purpose of the present invention to provide a generator of the kind described above, wherein the advantages of a directly driven, multipolar generator are preserved, and where the drawbacks connected with known generators are relieved such that it is possible not to have a stator housing as such whereby the diameter of the construction can be limited, and be made with a size substantially corresponding to the air gap diameter.

This purpose is achieved according to the present invention with a generator which is peculiar in that each single stator module is individually contained in an enclosure with a degree of sealing substantially corresponding to the degree of sealing which is desired in the finished generator, and that a given number of juxtaposed enclosures abutting on each other form a closed ring of stator modules.

By designing the generator according to the invention a number of advantages are attained as compared with the prior art.

The advantages of a directly driven, multipolar generator as compared with more conventional transmission systems with gearbox and standard generator are maintained in a generator according to the invention.

By designing the electrically active part of the generator stator as modules, each having the necessary degree of sealing (typically there is desired sealing corresponding to IP54), a stator housing as such is not necessary, the structural part of the stator housing adapted for mounting of the modules may be designed with an outer diameter substantially as the air gap diameter. Hereby the outer diameter of the part of the stator normally being installed when transporting the windmill to the erection site is reduced to the minimum determined by the air gap. Concerning the transport, there is a substantial advantage in having the least possible outer diameter. The winding modules of the stator then have to be retrofitted at the erection site.

By making the winding as modules, the space requirements and the complexity in the winding are reduced considerably. The stator modules may be performed in serial production, and the single modules may be finished with sealing, terminal box etc. under convenient conditions. Therefore, the risk becomes much less for winding damages caused by handling under difficult access conditions in a large construction.

A special embodiment of a stator module according to the invention is characterised in that the stator module is intended for constituting a part of a complete stator, and that

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the stator module is contained in an enclosure with tightness corresponding to a given desired degree of enclosure.

Description of the drawing

The invention is described more closely in the following as reference is made to the drawing, where:

Fig. 1 is an illustration of a prior art kind of tower top section of a windmill,

Fig. 2 is an illustration of an embodiment of a tower top section of a windmill with a generator according to the invention,

Fig. 3 is a detailed illustration of a generator according to the invention as seen perpendicularly to an axis of the generator,

Fig. 4 is a further detailed illustration of a generator according to the invention,

Fig. 5 is a detailed illustration of a generator according to the invention viewed in parallel with an axis of the generator,

Fig. 6 is a second detailed illustration of a generator according to the invention, and

Fig. 7 is an illustration of an embodiment of a stator module according to the invention.

In the design shown in the figures, the generator is with 120 poles in 24 stator modules. The generator is permanently magnetised. Other embodiments, including such with brushless as well as slipring magnetisation of a winded rotor, are also suitable. Here it may be relevant to design a winded rotor so that the rotor also has modules. Such a special embodiment is not described any further here.

Fig. 1 shows a prior art windmill in normal design with gearbox and standard generator. The wings 1 of the rotor are mounted on the mill hub 2 which is fastened to the main shaft 3. The main shaft is supported by a main bearing 4 at the front and by the gearbox 5 at the rear. The gearbox is connected to the generator 7 with an elastic coupling 6.

Fig. 2 shows a windmill designed according to the invention. The main shaft 8 is supported by a front main bearing 9 and a rear main bearing 10. The main bearing has a split bushing 11 as flange at the rear. The generator 12 has a shaft 14 (see fig. 3) which is supported by the flange 11 of the main shaft.

Fig. 3 shows an enlarged longitudinal section of the generator. The generator shaft 14 supports the structure 15 of the rotor which at its periphery has the rotor sheet metal 16 and the permanent magnets 17. The stator housing 18 is supported by the generator bearings 19 and has the stator modules 20 at its periphery.

Fig. 4 shows more enlarged a longitudinal section of the stator. The stator housing 18 is connected to the stator module 20 by a screw bolt connection (not shown). The stator module has an enclosure 23 around the stator sheet metal 24 and the stator winding 25. In the shown version, the generator is made with a stator housing having an outer diameter d which is exactly the same as an outer diameter of the rotor. The stator module is thus installed so that the stator module forms an inner diameter D which is greater than the outer diameter d of the rotor and of the rotor housing. An air gap A may easily be adjusted, e.g. by means of adjusting means, in the embodiment shown by means of shims 26, at the joint between stator housing and stator module, and possible dimensional deviations in the stator module may thereby be compensated for.

Fig. 5 shows in part a cross-section of the stator. The single pole 27 has a winding 28 and is protected by the enclosure 29. The single rotor pole 30 has a permanent magnet 17. In the rotor structure, manholes 32 are cut out for convenient passage of the generator.

Fig. 6 shows the complete generator as seen from the main shaft side. One of the stator modules 20 is shown dismantled. The other stator modules are at their respective places on the stator housing 18. Manholes 35 ensure the possibility of going through irrespectively of the position of the rotor. Fittings for torque supports 36 are provided with the same number as the stator modules whereby the stator of the generator may be fastened for vertical lowering of each single module.

The electric connection between the stator modules and is not shown on the Figure. It may e.g. be established in the way that there is mounted one central terminal box on the stator housing, and that from a terminal box on each stator module there is drawn an isolated three-phase cable from the stator module to the central terminal box. Alter-

natively, there may be established a connection form with three phase rings provided concentrically about the main shaft at one side of the stator housing under suitable covering. Isolated three-phase cables are drawn radially from the three phase rings to the terminal boxes of each of the stator modules, and the main cables transmitting the power to the frequency converter or directly to the network are installed directly on the phase rings.

Irrespectively of the local connections on the generator, it will be convenient to make the main cables from the generator with a certain slack that may absorb the displacements occurring between each stator module and a central terminal box if the stator of the generator is to be turned for each replacement of one or more stator modules. The slack may possibly be reduced for the stator to be capable of being turned only a half turn clockwise or counterclockwise depending on which side of a vertical plane the stator module to be replaced is situated.

Fig. 7 shows a stator module in cross-section and as end view. The pole 27 has its winding 28 and is protected by an enclosure 23. The assembled module 20 appears completely enclosed.

CLAIMS

1. Generator, preferably for a windmill and especially of the kind driven directly by the rotor of the windmill without any gearbox (5) installed between the rotor and the generator, wherein at least the stator of the generator (12) is made with at least two modules (20) which are fully enclosed and sealed, and that these at least two modules (20) may be mounted and dismantled independently of each other one or more at a time without dismantling the entire winding (25), characterised in that each single stator module (20) is individually contained in an enclosure (23) with a degree of sealing substantially corresponding to the degree of sealing which is desired in the finished generator (12), and that a given number of juxtaposed enclosures (23) abutting on each other form a closed ring of stator modules (20).

2. Generator according to claim 1, characterised in that each single stator module (20), when they are installed in a stator, together form a closed ring of stator modules having a diameter which does not substantially exceed the diameter of the air gap of the generator.

3. Generator according to claim 1 or 2, characterised in that each single stator module (20) may be displaced radially on the stator structure with the purpose of adjusting the air gap (A).

4. Generator according to any preceding claim, characterised in that the magnetic circuit in each single stator module is completely or substantially provided by iron having directional magnetic properties.

5. Generator according to any preceding claim, characterised in that the generator (12) is mounted on a shaft (14), and the stator during mounting and repair work may be turned in relation to the main shaft (8) of the windmill without this requiring substantial dismantling besides the moment support of the generator.

6. Generator according to any preceding claim, characterised in that the generator (12) during mounting and repair works may be turned in relation to a main shaft (8) of a windmill, in such a way that each single stator module (20) essentially may be lowered vertically to the ground or sea surface.

7. Generator according to any preceding claim, characterised in that the stator comprises between 2 and 48 modules (20), preferably 24 modules.

8. Generator according to claim 1, characterised in that the juxtaposed enclosures (23) have an inner surface facing inward toward the rotor (15) and forming the inner periphery (D) for the stator, that the inner periphery (D) of the stator is circular, that the rotor has an outer periphery (d) which is also circular, and that the air gap (A) between the outer periphery (D) of the rotor and the inner periphery (d) of the stator substantially have a constant width between 2 mm and 10 mm, preferably 5 mm.

9. Generator according to any preceding claim, characterised in that the width of the air gap (A) between the rotor and the stator may be adjusted individually for each stator module (20) and independently of each other by means of suitable adjusting means, e.g. shims (26), by adjusting a distance between an outer periphery (d) of the stator structure and an inner periphery (D) of a given stator module (20).

10. Stator module for use in a generator according to any preceding claim, which stator module comprises at least two poles and a number of windings around the poles, characterised in that the stator module is intended for constituting a part of a complete stator, and that the stator module is contained in an enclosure with a degree of sealing corresponding to a given desired degree of enclosure.

11. Use of a generator according to any preceding claim in a windmill.

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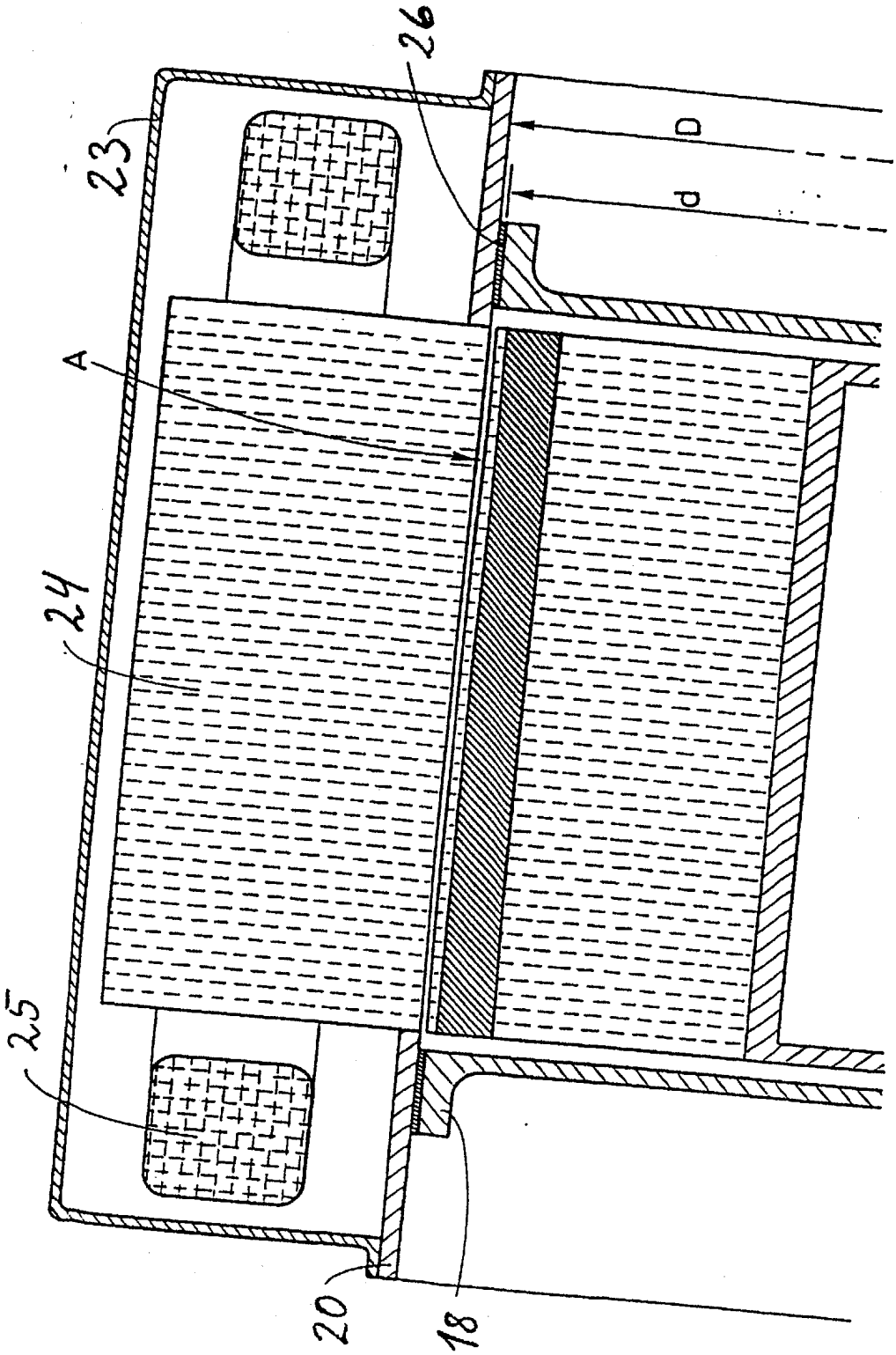

Fig.4

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- 4 APR. 2001

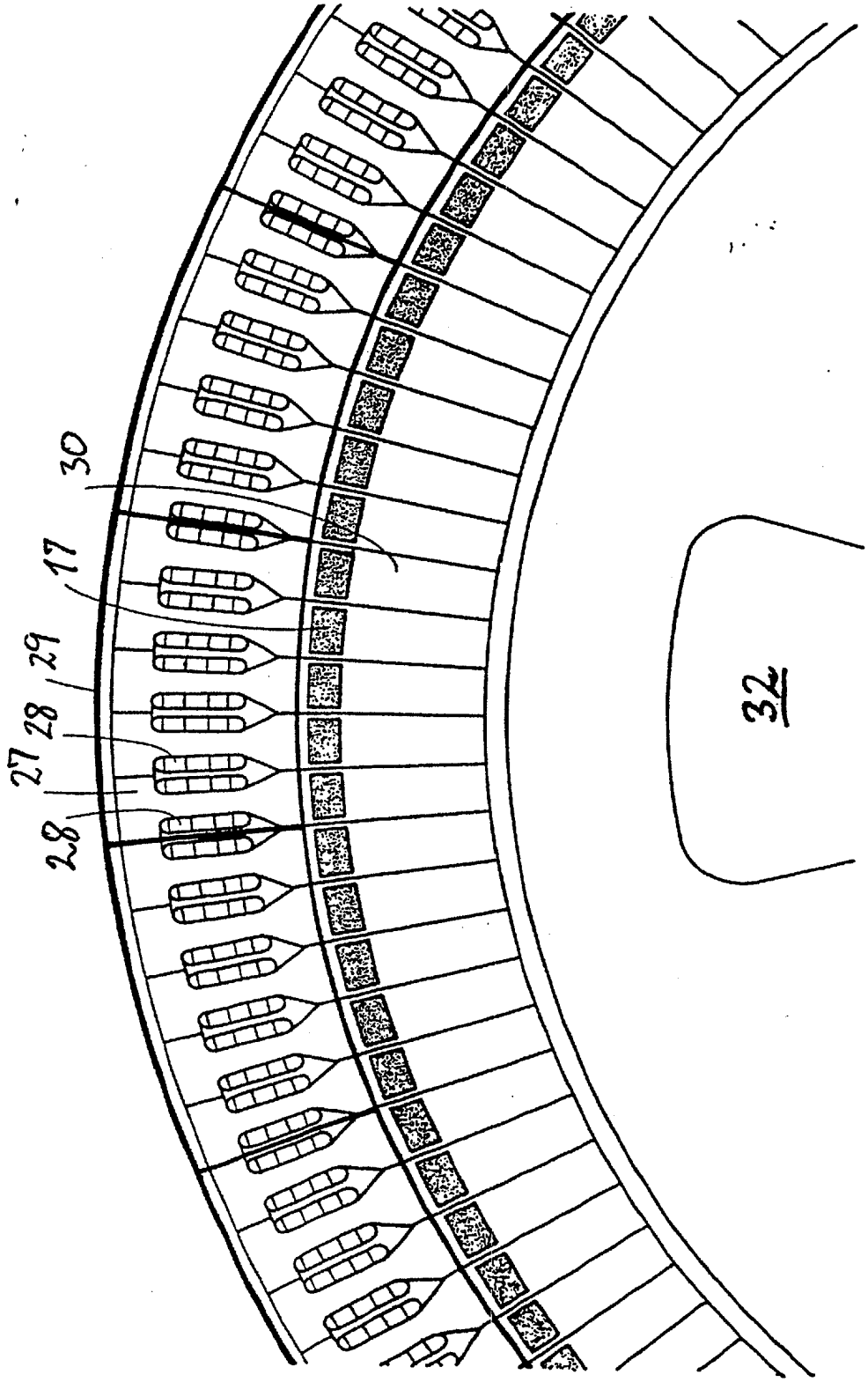

Fig.5

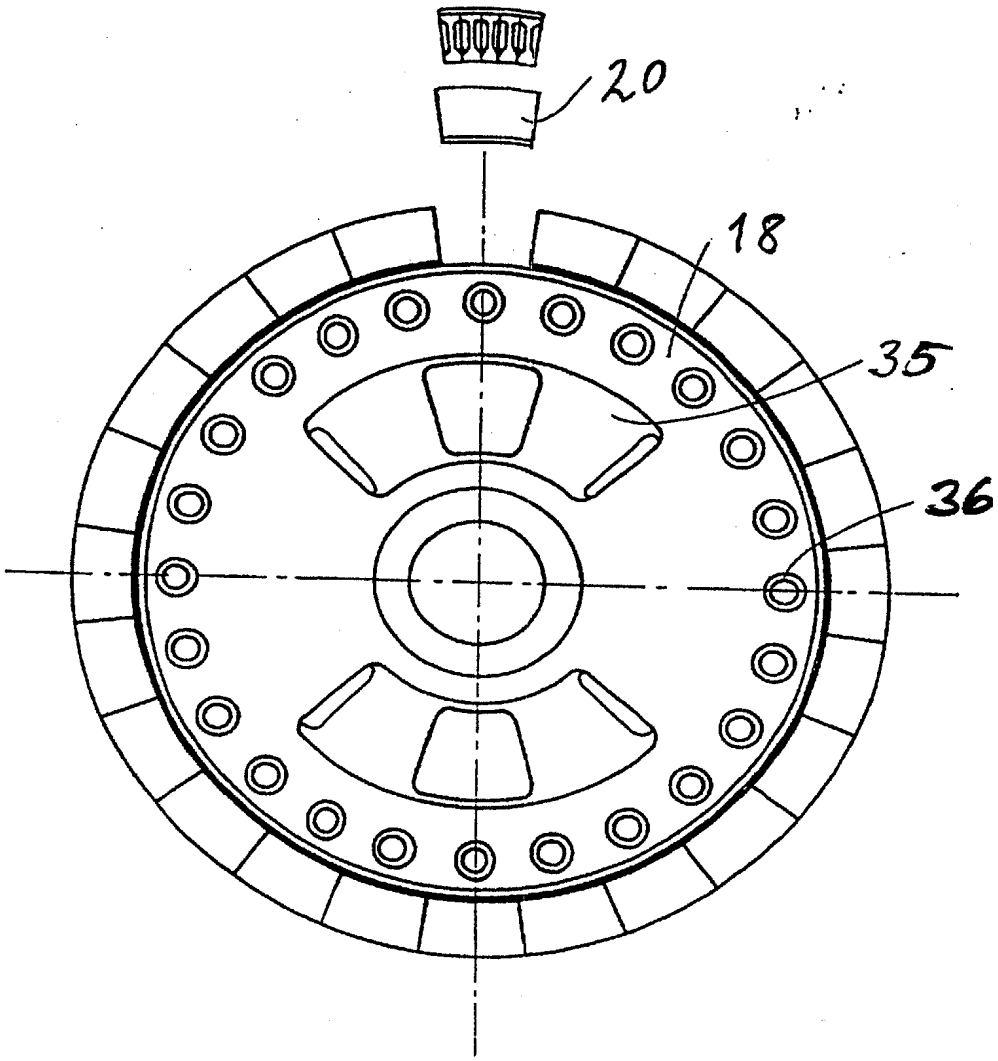

Fig.6

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- 3 APR. 2001

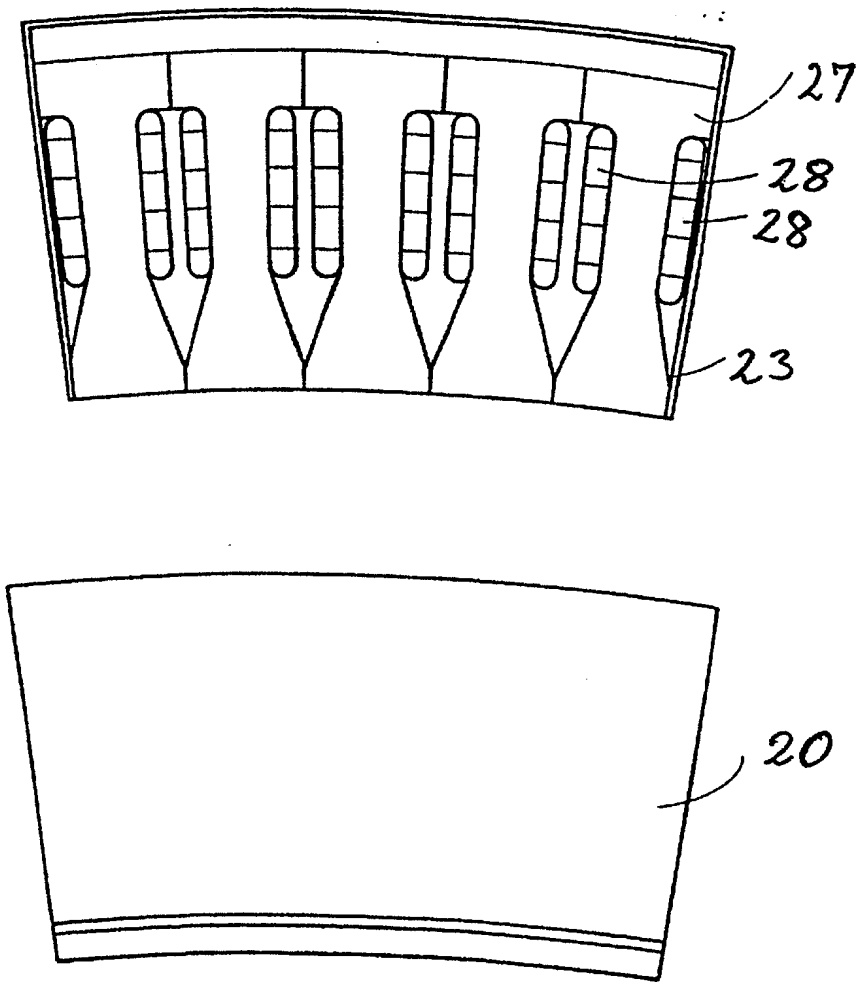

Fig.7

GENERATOR FOR A WINDMILL, STATOR MODULE FOR USE IN SUCH A GENERATOR AND USE OF SUCH A GENERATOR

Background of the invention

The present invention concerns to a generator for a windmill of the kind driven directly by the rotor of the windmill without any gearbox installed between the rotor and the generator. The invention also concerns a stator module for such a generator and a use of such a generator in a windmill.

It is known that it is necessary to insert a speed increasing gearbox between the rotor and the generator of a windmill. The rotational speed is of the magnitude 20 rpm for large windmills while a normal 4-pole generator has a synchronous speed of rotation of 1500 rpm. A suitable speed increasing gearbox will thus have a gear ratio of 1:75.

It is known that the speed increasing main gearbox of a windmill constitutes a substantial part of the cost price, and besides that it is a relatively vulnerable main component. In many cases, by possible damages, it will be necessary to dismantle the gearbox for repair. In consideration of the gearbox for a windmill in the 2 MW class having a weight of up to 15 tons and being mounted in a machine disposed on a tower with a height of 60-100 m it is obvious that such a replacement may be very costly.

The risk of incurring considerable expenses by a possible replacement is multiplied if large windmills are erected at sea. Handling of weights of 15 tons or more in 60-100 m height may only be performed with very large float cranes or very large mobile cranes placed on large barges. Working with this kind of equipment at the open sea can only be done under good weather conditions. Therefore, there may be periods of several months during the winter where it is not possible to replace a damaged gearbox.

The generator itself is also a heavy main component, typically with a weight of 5 tons by 2 MW rated output. As with the gearbox it cannot be avoided that there will be a

pact machine construction. In addition, here it will be necessary to dismantle the whole rotor by eventual dismantling of the generator.

There is known an embodiment of a directly driven generator, US patent 5,844,341, where the stator of the generator is made with modules which largely constitute individual polar pairs and which are disposed on support arms outside the poles. The advantage of this construction is that a damaged part of the generator may be replaced without taking down the whole generator. The drawback by this configuration is, however, that the electromechanical properties in this form of modular construction with single polar pairs separated by air gaps may be disadvantageous, and that possible dismantling of a single stator module can involve that the whole generator has to be opened in situ implying risk of humidity, dirt etc.. and that it may be cumbersome if the stator module has to be taken out in a disadvantageous direction.

Another design of a directly driven generator is known, US patent 4,866,321, where an axial generator has a stator designed with modules each containing a single pole winded around a coil and installed in an arrangement where the coil may be drawn radially out from the stator. The advantage of this construction is, as with the previous, that a damaged pole in the generator may be replaced without the whole generator to be taken down. As a consequence of the mechanical construction it is likely that the electromechanical properties will be better than in the above arrangement. The drawback is, however, that possible dismantling of a single stator module can involve that the whole generator has to be opened in situ implying risk of humidity, dirt etc., and that it may be cumbersome if the stator module has to be taken out in a disadvantageous direction.

It is the purpose of the present invention to provide a generator of the kind described above, preferably a directly driven, multipolar generator in a windmill, and where the drawbacks connected with known generators are relieved as the stator of the generator is more easy to install and to repair.

This purpose is achieved according to the present invention with a generator which is peculiar in that at least the stator of the generator is made with at least two modules which are fully enclosed and tight, and that these at least two modules may be mounted and dismantled independently of each other one or more at a time. Each of the least two modules contains at least two pairs of poles.

By designing the generator according to the invention a number of advantages are attained as compared with the prior art.

The advantages of a directly driven, multipolar generator as compared with more conventional transmission systems with gearbox and standard generator are maintained in a generator according to the invention.

By designing the electrically active part of the generator stator as modules, each having the necessary degree of sealing (typically there is desired sealing corresponding to IP54), the structural part of the stator housing may be designed with an outer diameter of a magnitude as the air gap diameter. Hereby the outer diameter of the part of the stator normally being installed when transporting the windmill to the erection site is reduced to the minimum determined by the air gap. Concerning the transport, there is a substantial advantage in having the least possible outer diameter. The winding modules of the stator then have to be retrofitted at the erection site.

By making the winding as modules, the space requirements and the complexity in the winding are reduced considerably. The stator modules may be performed in serial production, and the single modules may be finished with sealing, terminal box etc. under convenient conditions. Therefore, the risk becomes much less for winding damages caused by handling under difficult access conditions in a large construction.

A special embodiment of a stator module according to the invention is characterised in that the stator module is intended for constituting a part of a complete stator, and that the stator module is contained in an enclosure with tightness corresponding to a given desired degree of enclosure.

Description of the drawing

The invention is described more closely in the following as reference is made to the drawing, where:

Fig. 1 is an illustration of a prior art kind of tower top section of a windmill,

Fig. 2 is an illustration of an embodiment of a tower top section of a windmill with a generator according to the invention,

Fig. 3 is a detailed illustration of a generator according to the invention as seen perpendicularly to an axis of the generator,

Fig. 4 is a further detailed illustration of a generator according to the invention,

Fig. 5 is a detailed illustration of a generator according to the invention viewed in parallel with an axis of the generator,

Fig. 6 is a second detailed illustration of a generator according to the invention, and

Fig. 7 is an illustration of an embodiment of a stator module according to the invention.

In the design shown in the figures, the generator is with 120 poles in 24 stator modules. The generator is permanently magnetised. Other embodiments, including such with brushless as well as slipring magnetisation of a winded rotor, are also suitable. Here it may be relevant to design a winded rotor so that the rotor also has modules. Such a special embodiment is not described any further here.

Fig. 1 shows a prior art windmill in normal design with gearbox and standard generator. The wings 1 of the rotor are mounted on the mill hub 2 which is fastened to the main shaft 3. The main shaft is supported by a main bearing 4 at the front and by the gearbox 5 at the rear. The gearbox is connected to the generator 7 with an elastic coupling 6.

Fig. 2 shows a windmill designed according to the invention. The main shaft 8 is supported by a front main bearing 9 and a rear main bearing 10. The main bearing has a split bushing 11 as flange at the rear. The generator 12 has a shaft 13 which is supported by the flange 11 of the main shaft.

Fig. 3 shows an enlarged longitudinal section of the generator. The generator shaft 14 supports the structure 15 of the rotor which at its periphery has the rotor sheet metal 16 and the permanent magnets 17. The stator housing 18 is supported by the generator bearings 19 and has the stator modules 20 at its periphery.

Fig. 4 shows more enlarged a longitudinal section of the stator. The stator housing 21 is connected to the stator module 22 by a screw bolt connection (not shown). The stator module has an enclosure 23 around the stator sheet metal 24 and the stator winding 25. In the shown version, the generator is made with a stator housing having an outer diameter d which is exactly the same as an outer diameter of the rotor. The stator module is thus installed so that the stator module forms an inner diameter D which is greater than the outer diameter d of the rotor and of the rotor housing. An air gap A may easily be adjusted, e.g. by means of adjusting means, in the embodiment shown by means of shims 26, at the joint between stator housing and stator module, and possible dimensional deviations in the stator module may thereby be compensated for.

Fig. 5 shows in part a cross-section of the stator. The single pole 27 has a winding 28 and is protected by the enclosure 29. The single rotor pole 30 has a permanent magnet 31. In the rotor structure, manholes 32 are cut out for convenient passage of the generator.

Fig. 6 shows the complete generator as seen from the main shaft side. One of the stator modules 33 is shown dismantled. The other stator modules are at their respective places on the stator housing 24. Manholes 35 ensure the possibility of going through irrespectively of the position of the rotor. Fittings for torque supports 36 are provided with the same number as the stator modules whereby the stator of the generator may be fastened for vertical lowering of each single module.

The electric connection between the stator modules and is not shown on the Figure. It may e.g. be established in the way that there is mounted one central terminal box on the stator housing, and that from a terminal box on each stator module there is drawn an isolated three-phase cable from the stator module to the central terminal box. Alter-

natively, there may be established a connection form with three phase rings provided concentrically about the main shaft at one side of the stator housing under suitable covering. Isolated three-phase cables are drawn radially from the three phase rings to the terminal boxes of each of the stator modules, and the main cables transmitting the power to the frequency converter or directly to the network are installed directly on the phase rings.

Irrespectively of the local connections on the generator, it will be convenient to make the main cables from the generator with a certain slack that may absorb the displacements occurring between each stator module and a central terminal box if the stator of the generator is to be turned for each replacement of one or more stator modules. The slack may possibly be reduced for the stator to be capable of being turned only a half turn clockwise or counterclockwise depending on which side of a vertical plane the stator module to be replaced is situated.

Fig. 7 shows a stator module in cross-section and as end view. The pole 37 has its winding 38 and is protected by an enclosure 39. The assembled module 40 appears completely enclosed.

CLAIMS

1. Generator, preferably for a windmill and especially of the kind driven directly by the rotor of the windmill without any gearbox installed between the rotor and the generator, c h a r a c t e r i s e d in that at least the stator of the generator is made with at least two modules which are fully enclosed and tight, and that these at least two modules may be mounted and dismantled independently of each other one or more at the time.

2. Generator according to claim 1, c h a r a c t e r i s e d in that each single stator module are individually contained in an enclosure with a tightness substantially corresponding to the enclosing and tightness that is desired in the finished generator.

3. Generator according to claim 1 or 2, c h a r a c t e r i s e d in that each single stator module, when they are installed in a stator, together form a closed ring of stator modules having a diameter which does not substantially exceed the diameter of the air gap of the generator.

4. Generator according to claim 1, 2 or 3, c h a r a c t e r i s e d in that each single stator module may be displaced radially on the stator structure with the purpose of adjusting the air gap.

5. Generator according to any preceding claim, c h a r a c t e r i s e d in that the magnetic circuit in each single stator module is completely or substantially provided by iron having directional magnetic properties.

6. Generator according to any preceding claim, c h a r a c t e r i s e d in that the generator is mounted on a shaft, and the stator during mounting and repair work may be turned in relation to the main shaft of the windmill without this requiring substantial dismantling besides the moment support of the generator.

7. Generator according to any preceding claim, characterised in that the generator during mounting and repair works may be turned in relation to the shaft in such a way that each single stator module essentially may be lowered vertically to the ground or sea surface.

8. Generator according to any preceding claim, characterised in that the stator comprises between 2 and 48 modules, preferably 12 modules, that each module is contained in an enclosure, and that a given number of juxtaposed enclosures abutting on each other form a closed ring of stator modules.

9. Generator according to claim 8, characterised in that the juxtaposed enclosures have an inner surface facing inward toward the rotor and forming the inner periphery for the stator, that the inner periphery of the stator is circular, that the rotor has an outer periphery which is also circular, and that the air gap between the outer periphery of the rotor and the inner periphery of the stator substantially have a constant width between 2 mm and 10 mm, preferably 5 mm.

10. Generator according to any preceding claim, characterised in that the width of the air gap between the rotor and the stator may be adjusted individually for each stator module and independently of each other by means of suitable adjusting means, e.g. shims, by adjusting a distance between an outer periphery of the stator structure and an inner periphery of a given stator module.

11. Stator module for use in a generator according to any preceding claim, which stator module comprises at least two poles and a number of windings around the poles, characterised in that the stator module is intended for constituting a part of a complete stator, and that the stator module is contained in an enclosure with tightness corresponding to a given desired degree of enclosure.

12. Use of a generator according to any preceding claim in a windmill.

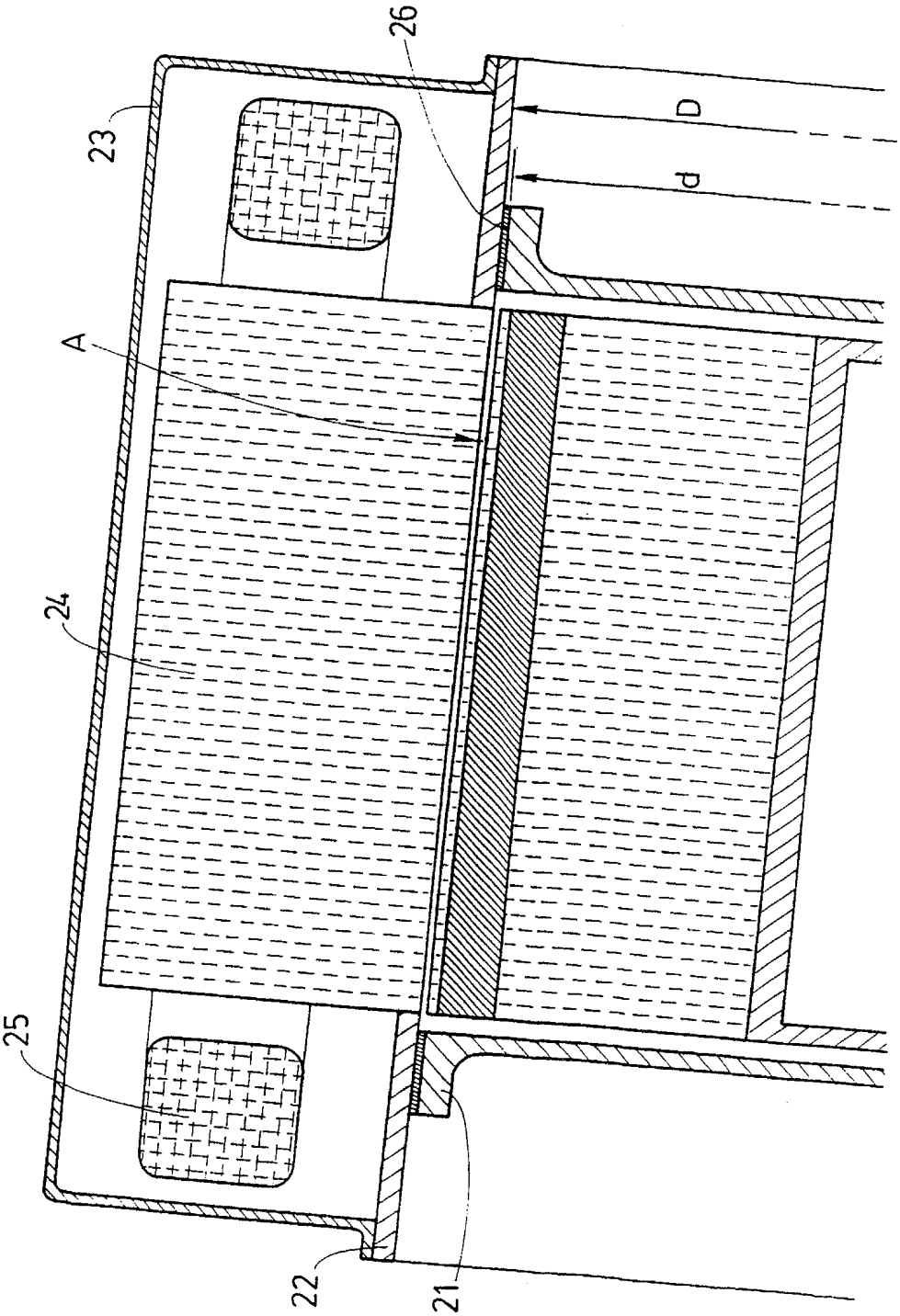

Fig.4

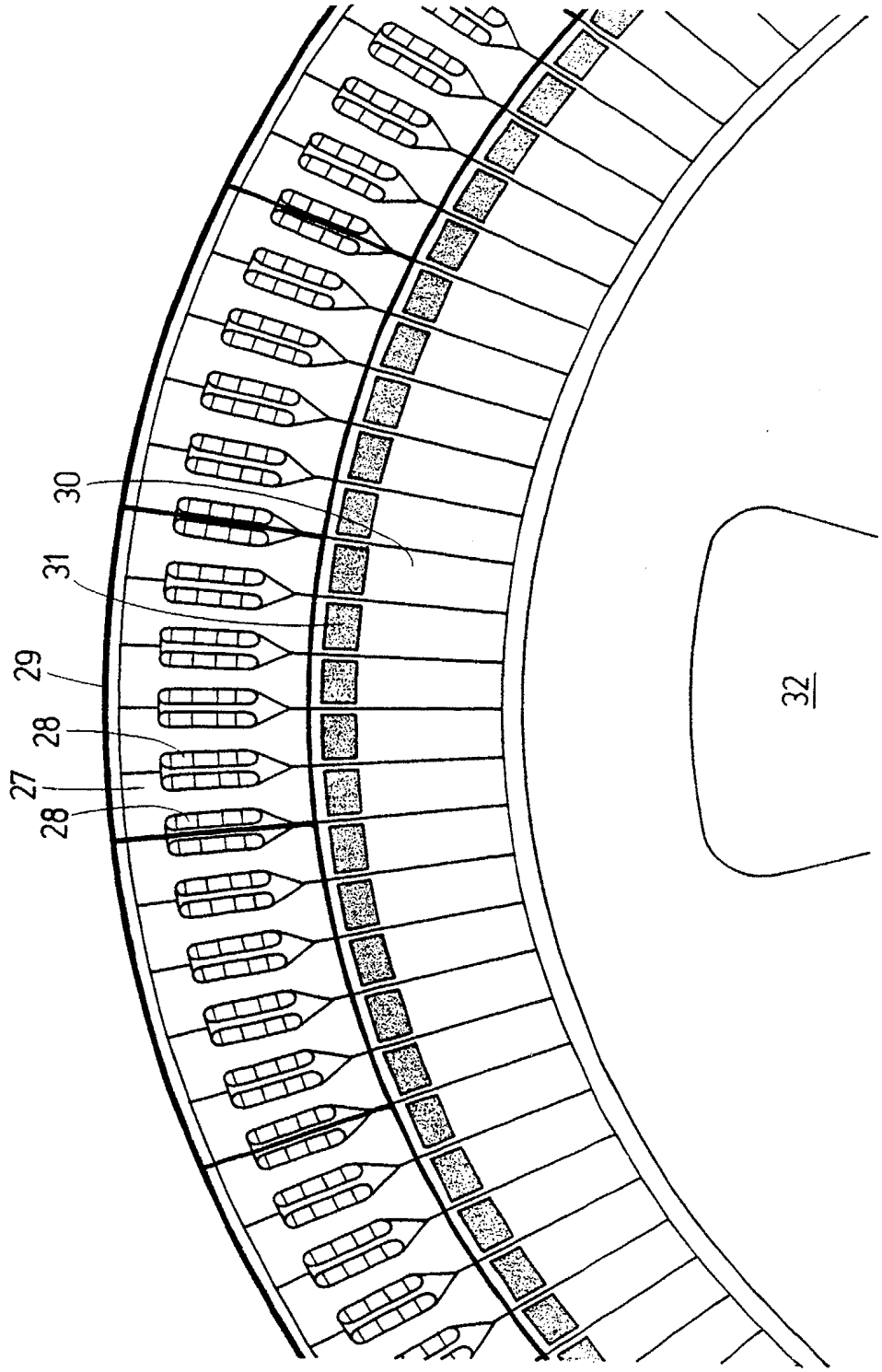

Fig.5

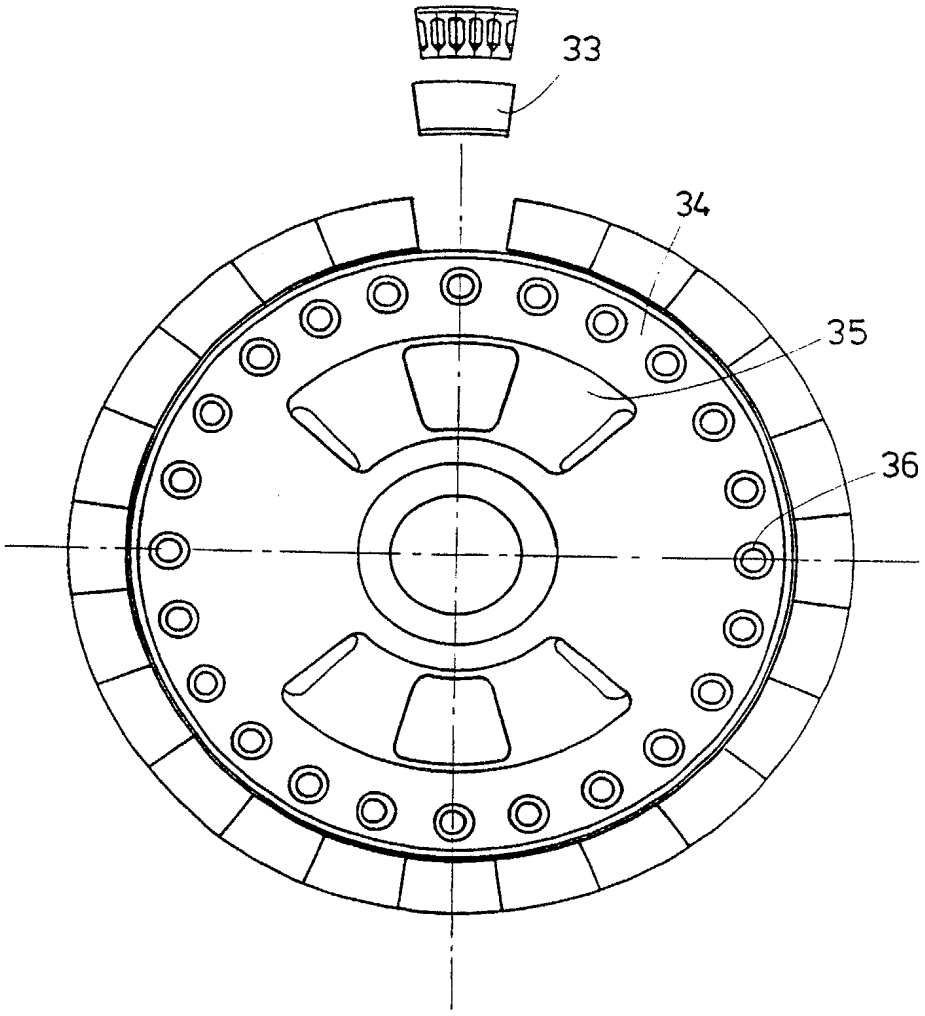

Fig.6

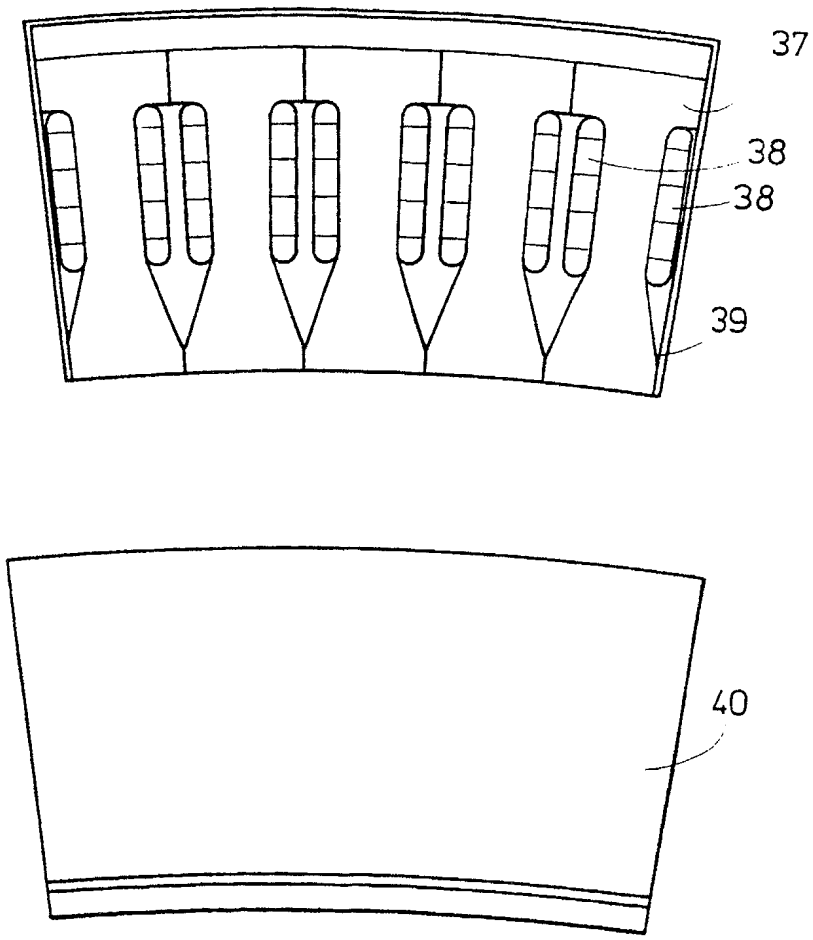

Fig.7

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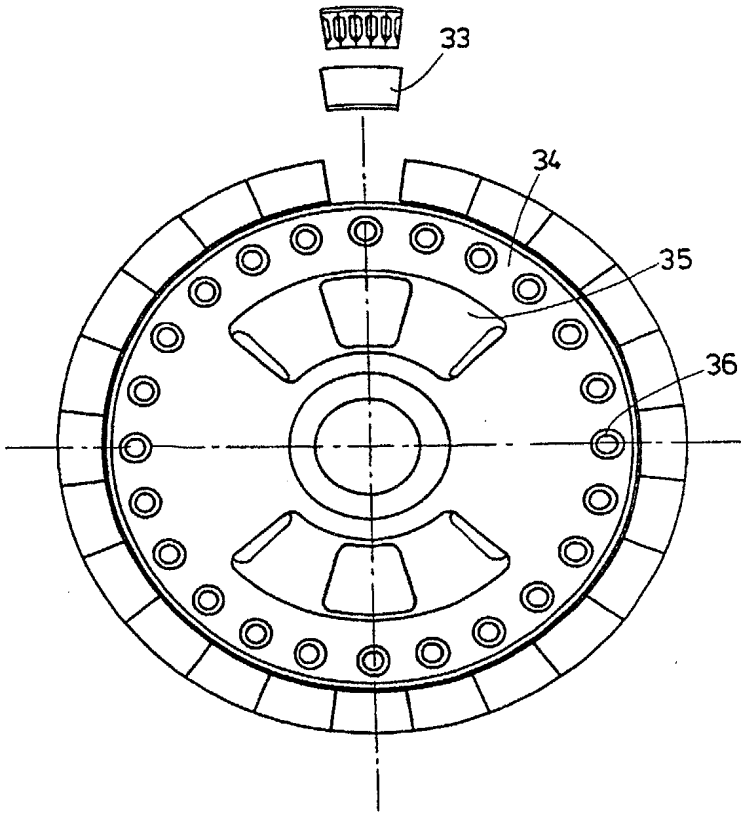
(54) Title: GENERATOR FOR A WINDMILL, STATOR MODULE FOR USE IN SUCH A GENERATOR AND USE OF SUCH A GENERATOR

(57) Abstract

The invention concerns a generator for a windmill. The generator is of the kind being directly coupled to the main shaft of the wind rotor of the windmill. The generator is a stator consisting of a number of stator modules that are individual and which may be installed, repaired and dismantled individually and independently of each other. This implies that it is very easy and thereby cheaper to mount the mill, especially at sea, as the stator for the generator can be transported in smaller units, which also makes it easier to assemble the stator in the tower top section. By subsequent repairs and other maintenance of the generator it is not necessary either to use large cranes, but it is sufficient to use smaller hoisting devices that may be handled by one or two persons.



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INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 00/00162

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H02K 1/12, H02K 15/02
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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4866321 A (HUBERT J. BLANCHARD ET AL), 12 Sept 1989 (12.09.89), column 1, line 57 - column 2, line 18; column 3, line 65 - line 66; column 4, line 8 - line 29	1-3,5-9, 11-12
X	US 5844341 A (EDWARD SPOONER ET AL), 1 December 1998 (01.12.98), column 4, line 16 - line 52; column 5, line 55 - line 58, figures 2,3, abstract	1,3,8,9

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO A9109446 (LENGD ELEKTROSILA) 1991-06-27 (abstract) World Patents Index (online) London, U.K.: Derwent Publications, Ltd. (retrieved on 2000-08-18) Retrieved from EPO WPI Database DW 199128 Accession No. 1991-208366 see abstract ---	1,3,8
X	WO 9820595 A1 (ASEA BROWN BOVERI AB), 14 May 1998 (14.05.98), page 15, line 28 - page 16, line 29, figure 4, abstract --- --------	1,3,8

INTERNATIONAL SEARCH REPORT

Information on patent family members

08/05/00

International application No.
PCT/DK 00/00162

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4866321 A	12/09/89	NONE	
US 5844341 A	01/12/98	CA 2124660 A	04/12/94
		DE 69401241 D,T	22/05/97
		DK 627805 T	20/01/97
		EP 0627805 A,B	07/12/94
		SE 0627805 T3	
		ES 2095718 T	16/02/97
		GB 2278738 A,B	07/12/94
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		JP 7075311 A	17/03/95
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		EP 0935837 A	18/08/99
		SE 9604026 A	05/05/98
		SE 9703718 A	14/04/99

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Date of mailing (day/month/year) 20 February 2001 (20.02.01)	
International application No. PCT/DK00/00162	**Applicant's or agent's file reference** P9797PC00/LN/ar
International filing date (day/month/year) 31 March 2000 (31.03.00)	**Priority date** (day/month/year) 31 March 1999 (31.03.99)
Applicant STIESDAL, Henrik et al	

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International Application No. PCT/DK00/00162

International Filing Date 31 MARCH 2000

Name of receiving Office and "PCT International Application" — Danish Patent and Trademark Office, PCT-International Application

Applicant's or agent's file reference *(if desired) (12 characters maximum)* P9797PC00/LN/ar

Box No. I TITLE OF INVENTION

Generator for a windmill, stator module for use in such a generator and use of such a generator

Box No. II APPLICANT

Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

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Facsimile No.

Teleprinter No.

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Knasterhovvej 21
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- [ ] all designated States except the United States of America
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Name and address: *(Family name followed by given name; for a legal entity, full official designation. The address must include postal code and name of country. The country of the address indicated in this Box is the applicant's State (that is, country) of residence if no State of residence is indicated below.)*

This person is:
- [ ] applicant only
- [ ] applicant and inventor
- [ ] inventor only *(If this check-box is marked, do not fill in below.)*

State *(that is, country)* of nationality:

State *(that is, country)* of residence:

This person is applicant for the purposes of:
- [ ] all designated States
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- [ ] Further applicants and/or (further) inventors are indicated on another continuation sheet.

Box No.V DESIGNATION OF STATES

The following designations are hereby made under Rule 4.9(a) *(mark the applicable check-boxes; at least one must be marked)*:

Regional Patent

☒ **AP** **ARIPO Patent:** **GH** Ghana, **GM** Gambia, **KE** Kenya, **LS** Lesotho, **MW** Malawi, **SD** Sudan, **SL** Sierra Leone, **SZ** Swaziland, **TZ** United Republic of Tanzania, **UG** Uganda, **ZW** Zimbabwe, and any other State which is a Contracting State of the Harare Protocol and of the PCT

☒ **EA** **Eurasian Patent:** **AM** Armenia, **AZ** Azerbaijan, **BY** Belarus, **KG** Kyrgyzstan, **KZ** Kazakhstan, **MD** Republic of Moldova, **RU** Russian Federation, **TJ** Tajikistan, **TM** Turkmenistan, and any other State which is a Contracting State of the Eurasian Patent Convention and of the PCT

☒ **EP** **European Patent:** **AT** Austria, **BE** Belgium, **CH and LI** Switzerland and Liechtenstein, **CY** Cyprus, **DE** Germany, **DK** Denmark, **ES** Spain, **FI** Finland, **FR** France, **GB** United Kingdom, **GR** Greece, **IE** Ireland, **IT** Italy, **LU** Luxembourg, **MC** Monaco, **NL** Netherlands, **PT** Portugal, **SE** Sweden, and any other State which is a Contracting State of the European Patent Convention and of the PCT

☒ **OA** **OAPI Patent:** **BF** Burkina Faso, **BJ** Benin, **CF** Central African Republic, **CG** Congo, **CI** Côte d'Ivoire, **CM** Cameroon, **GA** Gabon, **GN** Guinea, **GW** Guinea-Bissau, **ML** Mali, **MR** Mauritania, **NE** Niger, **SN** Senegal, **TD** Chad, **TG** Togo, and any other State which is a member State of OAPI and a Contracting State of the PCT *(if other kind of protection or treatment desired, specify on dotted line)* .....

National Patent *(if other kind of protection or treatment desired, specify on dotted line)*:

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☒ **AL** Albania .....
☒ **AM** Armenia .....
☒ **AT** Austria .....and Utility Model...
☒ **AU** Australia .....
☒ **AZ** Azerbaijan
☒ **BA** Bosnia and Herzegovina .....
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Box No. VI PRIORITY CLAIM ☐ Further priority claims are indicated in the Supplemental Box.

Filing date of earlier application (day/month/year)	Number of earlier application	Where earlier application is: national application: country	regional application:* regional Office	international application: receiving Office
item (1) (31.03.1999) 31st March 1999	PA 1999 00451	DK		
item (2) (17.11.1999) 17th November 1999	PA 1999 01655	DK		
item (3)				

☒ The receiving Office is requested to prepare and transmit to the International Bureau a certified copy of the earlier application(s) *(only if the earlier application was filed with the Office which for the purposes of the present international application is the receiving Office)* identified above as item(s): (1) and (2)

* *Where the earlier application is an ARIPO application, it is mandatory to indicate in the Supplemental Box at least one country party to the Paris Convention for the Protection of Industrial Property for which that earlier application was filed (Rule 4.10(b)(ii)). See Supplemental Box.*

Box No. VII INTERNATIONAL SEARCHING AUTHORITY

Choice of International Searching Authority (ISA) *(if two or more International Searching Authorities are competent to carry out the international search, indicate the Authority chosen; the two-letter code may be used):*

ISA / SE

Request to use results of earlier search; reference to that search *(if an earlier search has been carried out by or requested from the International Searching Authority):*

Date *(day/month/year)* Number Country *(or regional Office)*

Box No. VIII CHECK LIST; LANGUAGE OF FILING

This international application contains the following **number of sheets:**

request	:	4
description (excluding sequence listing part)	:	9
claims	:	2
abstract	:	1
drawings	:	7
sequence listing part of description	:	
Total number of sheets	:	23

This international application is **accompanied by** the item(s) marked below:

1. ☒ fee calculation sheet
2. ☒ separate signed power of attorney
3. ☐ copy of general power of attorney; reference number, if any:
4. ☐ statement explaining lack of signature
5. ☐ priority document(s) identified in Box No. VI as item(s):
6. ☐ translation of international application into (language):
7. ☐ separate indications concerning deposited microorganism or other biological material
8. ☐ nucleotide and/or amino acid sequence listing in computer readable form
9. ☒ other *(specify)*: Copy of Official Letter of February 29, 2000

Figure of the drawings which should accompany the abstract: 6

Language of filing of the international application: Danish

Box No. IX SIGNATURE OF APPLICANT OR AGENT

Next to each signature, indicate the name of the person signing and the capacity in which the person signs (if such capacity is not obvious from reading the request).

Aarhus C, March 31, 2000

Anne Ramskov

PATRADE A/S

Anne Ramskov (secretary)

1. Date of actual receipt of the purported international application: RO/DK 31 MAR 2000 (31.03.00)
2. Drawings: ☐ received: ☐ not received:
3. Corrected date of actual receipt due to later but timely received papers or drawings completing the purported international application:
4. Date of timely receipt of the required corrections under PCT Article 11(2):
5. International Searching Authority (if two or more are competent): ISA / SE
6. ☐ Transmittal of search copy delayed until search fee is paid.

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Date of receipt of the record copy by the International Bureau: 18 APRIL 2000 (18.04.00)

PCT/DK 00/00162
RO/DK 15 JUN 2001

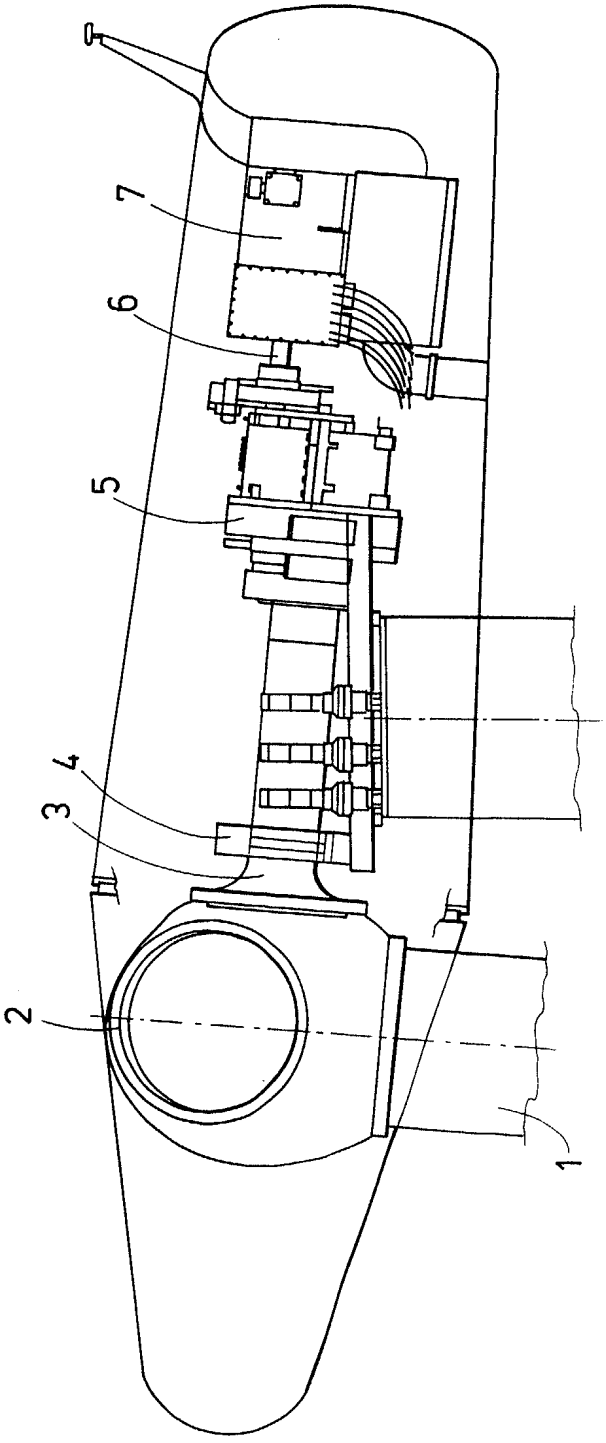

Fig.1

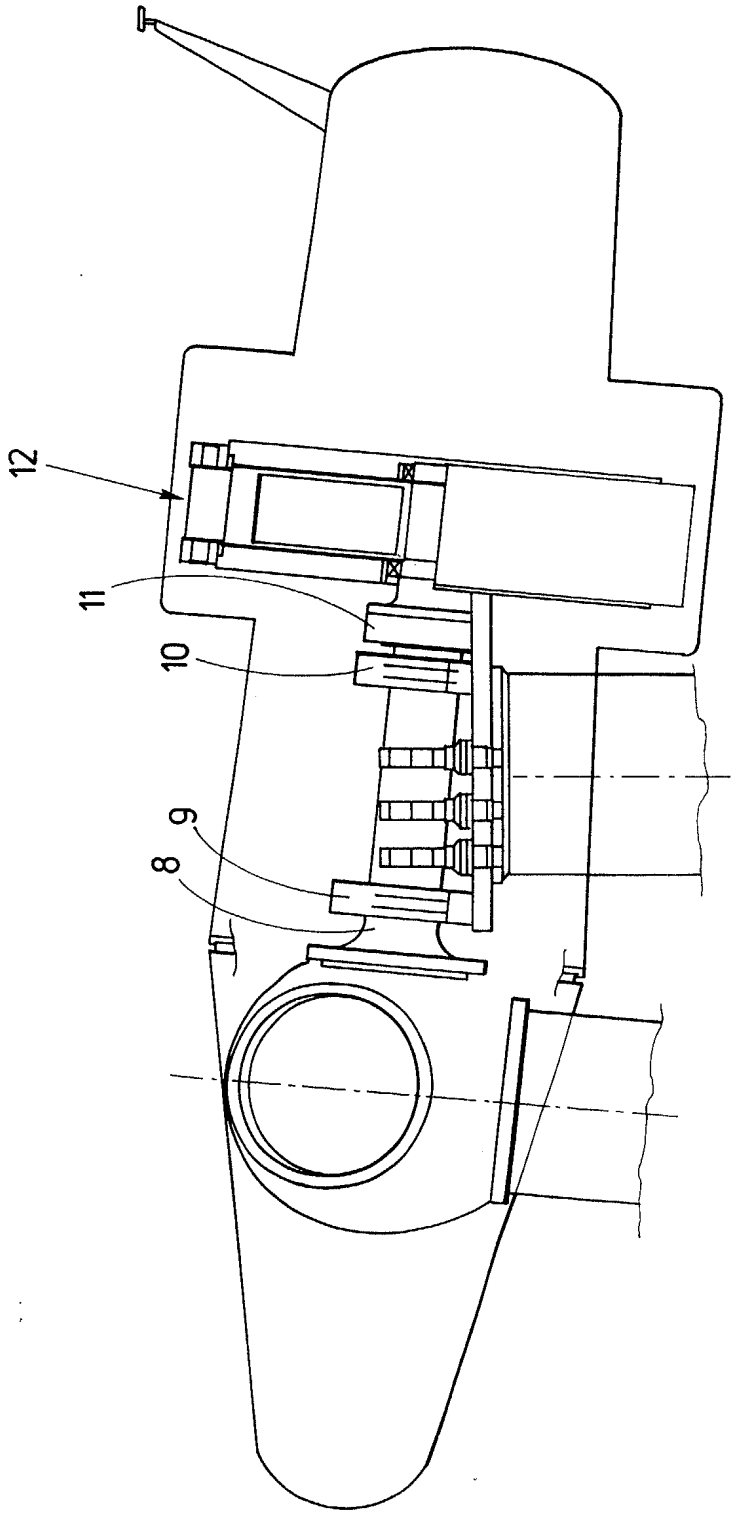

Fig.2

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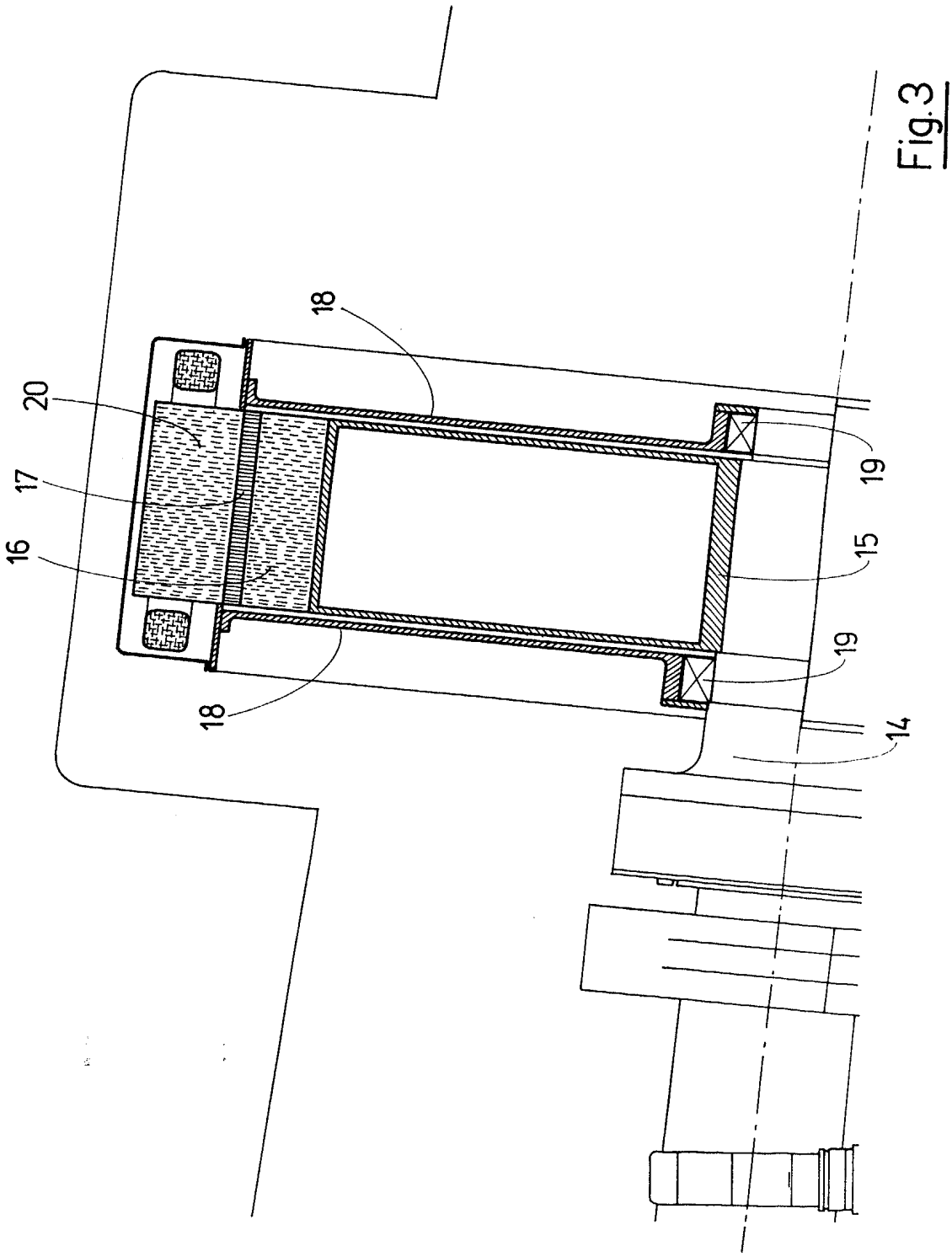

Fig.3

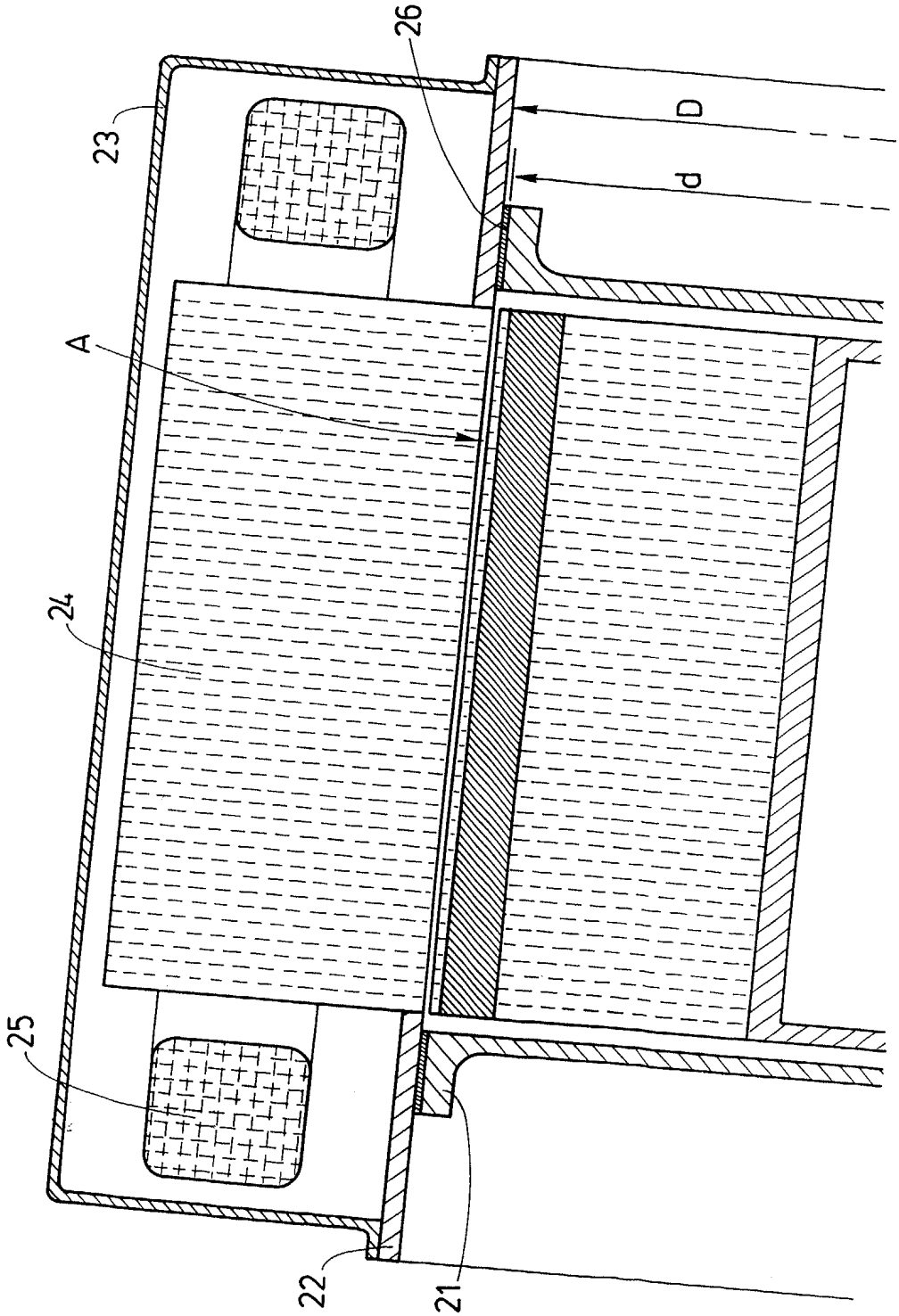

Fig.4

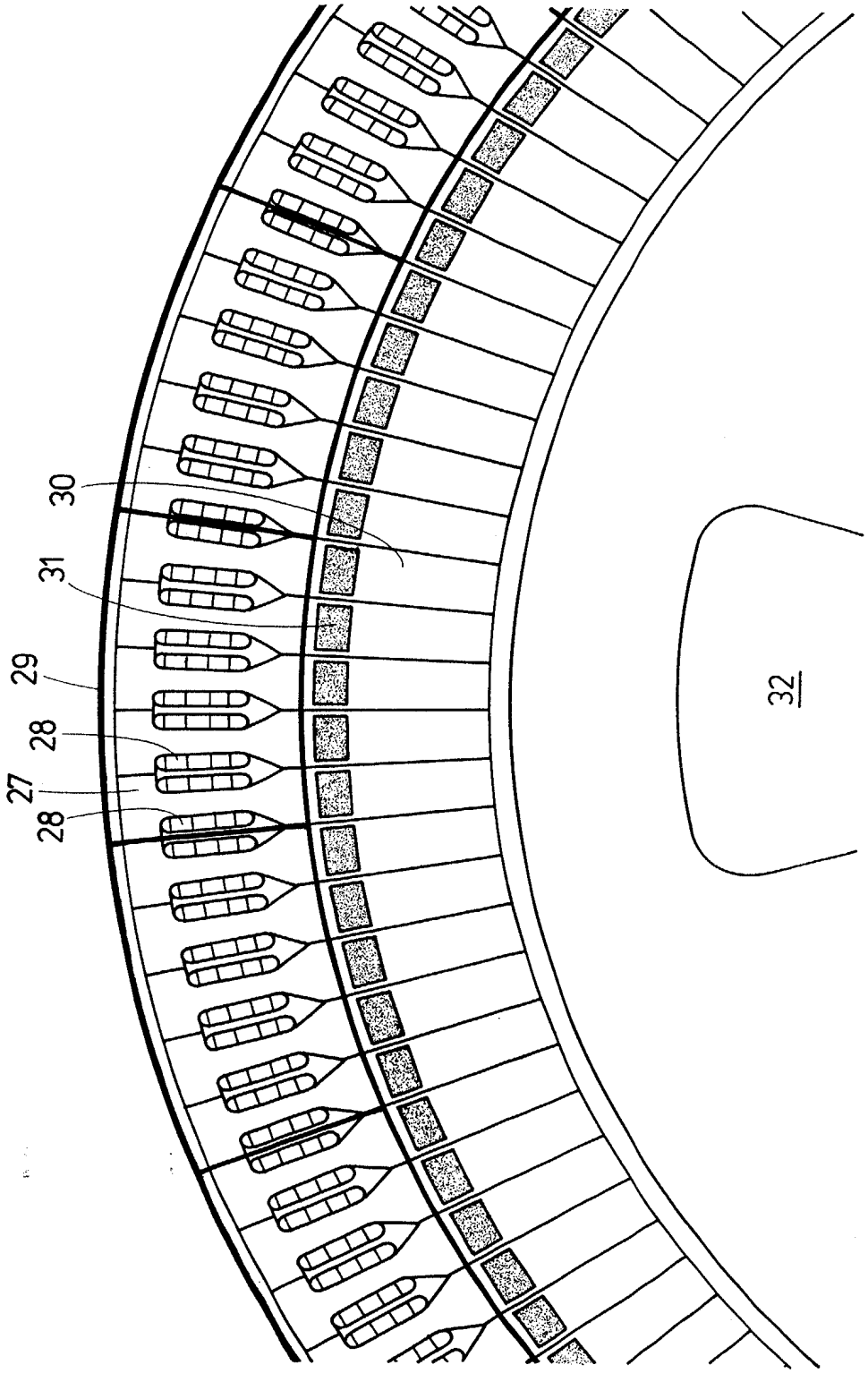

Fig.5

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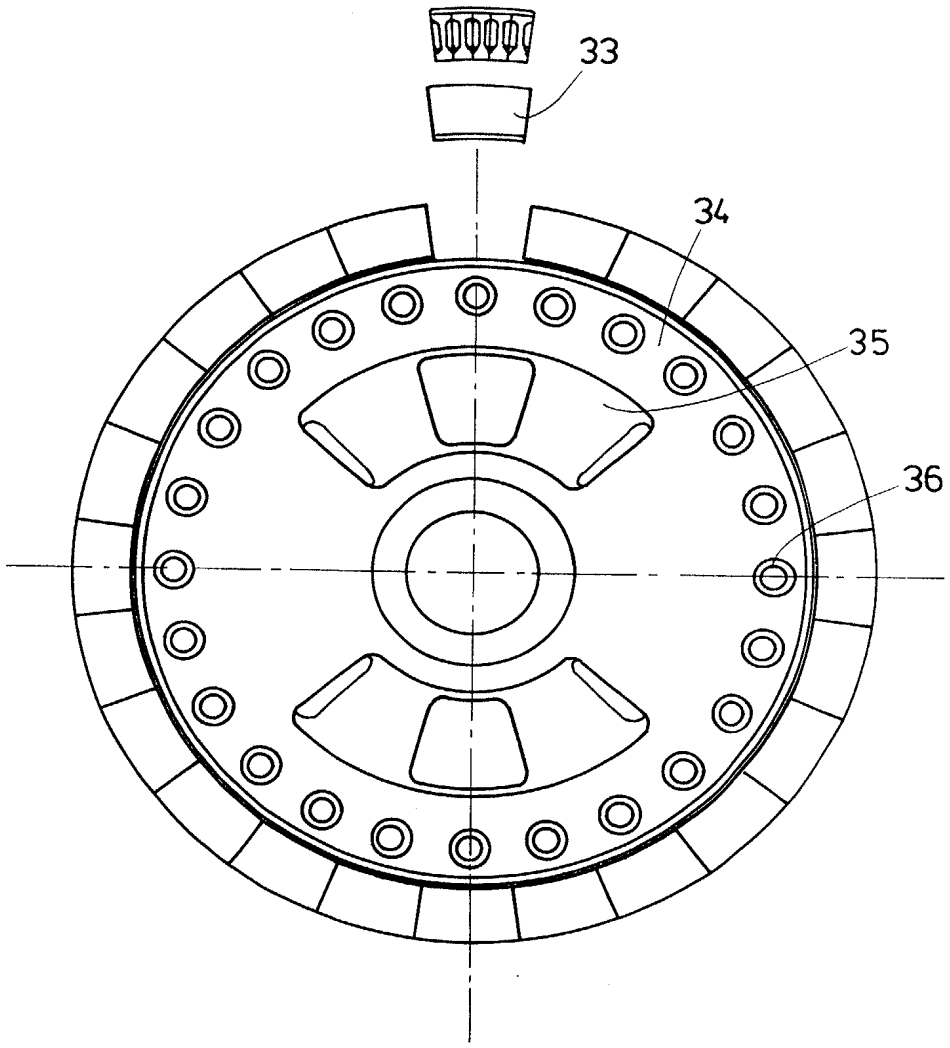

Fig.6

PCT/DK 00/00162
RO/DK 15 JUN 2000

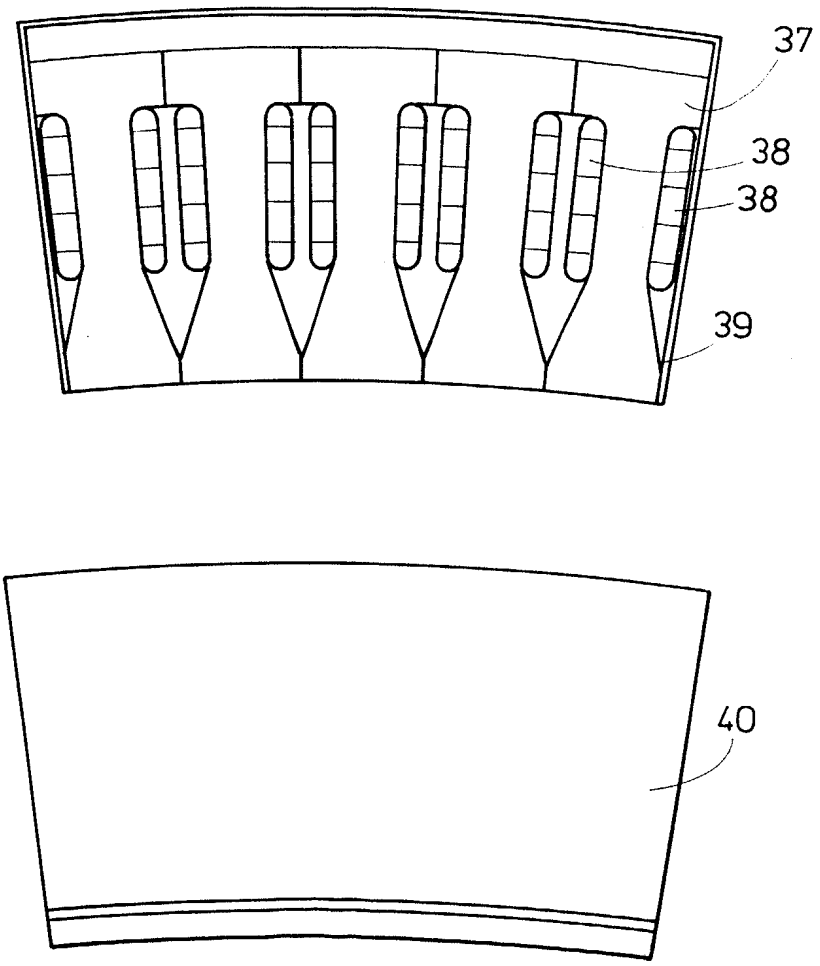

Fig.7

GENERATOR TIL EN VINDMØLLE, STATORMODUL TIL BRUG I EN SÅDAN GENERATOR SAMT ANVENDELSE AF EN SÅDAN GENERATOR.

Opfindelsens baggrund

Opfindelsen angår en generator til en vindmølle af den art, der drives direkte af vindmøllens rotor uden gear monteret mellem rotoren og generatoren. Opfindelsen angår også et statormodul til en sådan generator samt en anvendelse af en sådan generator i en vindmølle.

Det er kendt, at det normalt er nødvendigt at indskyde et fartforøgende gear mellem en vindmølles rotor og dens generator. Rotorens omløbshastighed er for store vindmøller af størrelsesordenen 20 o/min, mens en normal 4-polet generator har et synkront omløbstal på 1500 o/min. Et passende fartforøgende gear vil således have et udvekslingsforhold på 1:75.

Det er kendt, at det fartforøgende hovedgear på en vindmølle udgør en væsentlig del af kostprisen, og at det i øvrigt er en forholdsvis sårbar hovedkomponent. Ved eventuelle skader vil det i mange tilfælde være nødvendigt at afmontere gearet for reparation. I betragtning af, at gearet til en vindmølle i 2 MW klassen har en vægt på op mod 15 tons, og at det er monteret i en maskine, der er anbragt på et tårn med en højde på 60-100 m, er det indlysende, at sådan udskiftning kan være meget bekostelig.

Risikoen for, at der løber betydelige udgifter på ved eventuel udskiftning, bliver mangedoblet, hvis store vindmøller opstilles til havs. Håndtering af vægte på 15 tons eller mere i 60-100 m højde kan kun udføres med meget store flydekraner eller meget store mobilkraner anbragt på store pramme. Arbejde med den slags udstyr på åbent hav kan kun udføres under gode vejrforhold. Der kan derfor være perioder af måneders varighed om vinteren, hvor det ikke kan lade sig gøre at udskifte et beskadiget gear.

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Generatoren selv er også en tung hovedkomponent, typisk med en vægt på 5 tons ved 2 MW mærkeeffekt. Ligesom ved gearet kan det ikke undgås, at der vil være en vis risiko for havari på generatoren. Forholdene ved udskiftning af denne er lige så ugunstige som for gearet.

Det er også kendt, at der findes gearløse transmissionssystemer til vindmøller, hvor gear og generator erstattes af en langsomtløbende, mangepolet generator. En sådan direkte drevet generator kan udføres som en synkrongenerator med viklet rotor eller med permanente magneter, eller den kan udføres som alternative typer generatorer. Fælles for direkte drevne, mangepolede generatorer er, at deres dimensioner er store. Luftspaltediameteren ved 2 MW mærkeeffekt kan f.eks. være af størrelsesordenen 5 m ved en udførelse med viklet rotor, og lidt mindre ved en udførelse med permanent magnetiseret rotor.

Med en direkte drevet, mangepolet generator bliver gearet overflødigt. Det vil som regel være nødvendigt at indskyde en frekvensomformer mellem generatoren og nettet, da det er vanskeligt at opnå et polantal svarende til 50 Hz netfrekvensen ved nominelt omløbstal. Derfor genererer mangepolede generatorer normalt vekselstrøm med en noget lavere frekvens, f.eks. 20 Hz, hvorved antallet af poler kan reduceres til 2/5, og der bliver bedre plads til spoleviklingerne. Selv om frekvensomformeren udgør en forøget kompleksitet i forhold til et generatorsystem, hvor generatoren er koblet direkte til nettet, kan man anlægge den vurdering, at reduktionen i kompleksitet ved bortfaldet af hovedgearet mere end opvejer dette.

En væsentlig ulempe ved en direkte drevet, mangepolet generator er de fysiske dimensioner. Med en luftspaltediameter på 5 m bliver yderdiameteren af størrelsesordenen 6 m, og egenvægten bliver omtrent som egenvægten af de komponenter, der erstattes, gear og normal generator, altså 20 tons eller mere. Den store yderdiameter vanskeliggør transport, og egenvægten gør ikke problemet med udskiftning for reparation ved eventuelle havarier mindre.

En yderligere vanskelighed opstår i de normale konfigurationer med mangepolede generatorer, hvor generatoren er anbragt mellem rotoren og tårnet for at give en kompakt maskinkonstruktion. Her vil det oven i købet være nødvendigt at afmontere hele rotoren ved eventuel demontage af generatoren.

Der kendes en udførelse af en direkte drevet generator, US patent 5,844,341, hvor generatorens stator er udført med moduler, der i det store udgør individuelle polpar, og som er anbragt på bærearme anordnet udenfor polerne. Fordelen ved denne konstruktion er, at en skadet del af generatoren kan udskiftes, uden at hele generatoren skal nedtages. Ulempen ved denne konfiguration er imidlertid, at de elektromekaniske egenskaber ved denne form for modulopbygning med enkelte polpar, der er adskilt af luftspalter, kan være ugunstige, og at eventuel demontage af et enkelt statormodul dels vil medføre, at hele generatoren skal åbnes in situ, med hvad dette indebærer af risiko for fugt, snavs m.v., dels kan være besværlig, hvis statormodulet skal udtages i en ugunstig retning.

Der kendes en anden udførelse af en direkte drevet generator, US patent 4,866,321, hvor en aksialgenerator har en stator, der er udført med moduler, som hver indeholder en enkelt pol viklet om en spole og monteret i et arrangement, så spolen kan udtrækkes radialt fra statoren. Fordelen ved denne konstruktion er, som ved den foregående, at en skadet pol i generatoren kan udskiftes uden at hele generatoren skal nedtages. I medfør af den mekaniske konstruktion er det sandsynligt, at de elektromekaniske egenskaber vil være bedre end i ovenstående arrangement. Ulempen er imidlertid som ovenfor, at eventuel demontage af et enkelt statormodul dels vil medføre, at hele generatoren skal åbnes in situ, med hvad dette indebærer af risiko for fugt, snavs m.v., dels kan være besværlig, hvis statormodulet skal udtages i en ugunstig retning.

Det er formålet med den foreliggende opfindelse at tilvejebringe en generator af den ovenfor beskrevne type, fortrinsvis en direkte drevet, mangepolet generator i en vindmølle, og hvor ulemperne, der er forbundet med kendte generatorer er afhjulpet, idet generatorens stator er nemmere at montere og reparere.

Dette formål opnås ifølge den foreliggende opfindelse med en generator, som er særpræget ved, at i det mindste generatorens stator er udført med mindst to moduler, som er kapslede og tætte, og at disse mindst to moduler kan monteres og afmonteres uafhængigt af hinanden et eller flere ad gangen. Hver af de mindst to moduler indeholder i det mindste to polpar.

Ved at udforme generatoren ifølge opfindelsen opnås en række fordele i forhold til den kendte teknik.

De fordele, en direkte drevet, mangepolet generator har i forhold til mere konventionelle transmissionssystemer med gear og standardgenerator, bevares i en generator ifølge opfindelsen.

Ved at udføre generatorens statorens elektrisk aktive del i moduler, der hver har den fornødne tæthedsgrad (typisk ønskes tæthed svarende til IP54), kan den strukturelle del af statorhuset udføres med en yderdiameter, der er af størrelsesorden som luftspaltediameteren. Herved reduceres yderdiameteren af den del af statoren, der normalt skal være monteret ved transport af vindmøllen til opstillingsstedet, til det minimum, der fastlægges af luftspalten. Hvad transporten angår, er der en væsentlig fordel i at have den mindst mulige yderdiameter. Statorens viklingsmoduler skal da eftermonteres på opstillingsstedet.

Ved at udføre viklingen i moduler, reduceres pladsbehovet og kompleksiteten i viklingen meget betydeligt. Statormodulerne kan udføres i serieproduktion, og de enkelte moduler kan under bekvemme forhold gøres færdig med tætning, klemkasse m.v. Risikoen bliver derfor meget mindre for viklingsskader, der forårsages af håndtering under vanskelige adgangsforhold i en stor konstruktion.

En speciel udførelsesform for et statormodul ifølge opfindelsen er kendetegnet ved, at statormodulet er bestemt til at udgøre en del af en hel stator, og at statormodulet er indeholdt i en indkapsling svarende til en ønsket kapslingsgrad for den færdige generator.

Ved at udføre statormodulerne med den fornødne tætning, så de kan på- og afmonteres in situ, opnås en meget væsentlig fordel ved eventuelle skader. Skader på en generatorvikling opstår normalt ved et initialt overslag på ét lokaliseret sted, f.eks. på grund af tilfældige isolationsskader, fugt eller lignende. På grund af de store energimængder, der frigives ved en afbrænding, får skaden imidlertid typisk mere generelle virkninger på hele viklingen i en standardgenerator. Store dele af viklingen kan skades ved afsmeltning, andre termiske effekter og tilsodning. Det er derfor normal praksis, at hele viklingen udskiftes, når der optræder en skade. I den modulopbyggede generator vil skaden derimod normalt kunde begrænses til netop det modul, hvor det initiale overslag forekom. Det er således ikke nødvendigt, at hele viklingen afmonteres, idet reparationen kan begrænses til det(de) pågældende modul(er).

Den segmenterede opbygning af generatoren giver mulighed for udnyttelse af særlig gunstige materialeegenskaber, der normalt ikke er til rådighed ved roterende elektriske maskiner. Sagen er, at der kan fremstilles jern med retningsbestemte magnetiske egenskaber. Denne type feltorienteret jern anvendes i transformatorer, og betegnes derfor normalt som transformatorblik. På en normal roterende maskine, hvor blik til stator og rotor udstanses i ét stykke, kan transformatorblik ikke anvendes, idet magnetfeltlinjerne vil få alle retninger omkring rotoraksen. Fordelen ved de gode magnetiske egenskaber i den mest gunstige feltretning bliver derfor mere end bortkompenseret af tilsvarende dårlige magnetiske egenskaber vinkelret på den mest gunstige feltretning. Derfor bruges såkaldt motorblik, der ikke har retningsbestemte magnetiske egenskaber, på roterende maskiner. Jerntabene er derfor noget større på roterende maskiner end på transformatorer med tilsvarende fluxvariationer.

På den segmenterede generator forholder det sig imidlertid anderledes end på normale roterende maskiner. Ved at udføre generatoren med seks eller flere statormoduler, kan det opnås, at magnetfeltlinjerne indenfor hvert segment ikke vil afvige stort mere end 10 grader fra den mest gunstige retning i jernet. Anvendelse af transformatorblik bliver derfor relevant, og derved opnås mulighed for en betydelig reduktion af magnetiseringstabene sammenlignet med tabene ved brug af generatorblik. Desuden

opnås bedre magnetisk ledeevne, hvorved der fås højere induktion og feltstyrke i luftgabet med større magnetiske kraft og drejningsmoment til følge.

Ved selve håndteringen opnås også væsentlige fordele. Det enkelte modul vil nemlig have en vægt, der er meget mindre end vægten af den komplette generator, og også meget mindre end vægten af et normalt gear eller en normal generator. Ved en direkte drevet, mangepolet generator med en vægt på 20 tons, kan modulerne bekvemt udføres i et antal, så de hver får en vægt på 500 kg. Med en vægt af denne størrelsesorden kan modulerne udskiftes enkeltvis af nogle få montører med hjælp af en lille kran, der med fordel kan være indbygget i kabinen i en vindmølle.

Fordelen i forhold til kendt teknik er navnlig væsentlig, hvor store vindmøller opstilles til havs. De meget store flydekraner eller meget store mobilkraner anbragt på store pramme, der er nødvendige ved reparationsarbejder på kendte transmissionssystemer, hvad enten disse er konventionelle med gear og standardgenerator, eller er med direkte drevne, mangepolede generatorer, kan helt undgås. Eneste forudsætning for reparation er, at det er muligt at få servicepersonale på møllen. Udskiftede generatormoduler kan nedfires med en lille indbygget kran, og de kan sejles til og fra vindmøllen på en normal servicebåd. Der kan endda opbevares et antal generatormoduler i mølletoppen som reservedele, hvorved nedfiring og søtransport kan udskydes til perioder med gunstige vejrforhold.

Ved at udføre generatoren i en akselmonteret udgave, hvor drejningsmomentet optages i nogle specifikke punkter af momentstøtter, kan der opnås den fordel, at generatorens stator kan drejes til den mest optimale stilling ved reparationsarbejder. Montage og demontage af moduler kan derfor ske i én bestemt position, uanset hvor på generatoren det enkelte modul er anbragt, når generatoren er i sin normale driftsstilling. Eksempelvis kan generatorens stator drejes, så det modul, der skal udskiftes, vender nedad og derfor umiddelbart kan fires ned gennem en lem i bunden af vindmøllens kabine.

Tegningsbeskrivelse

I det følgende beskrives opfindelsen nærmere, idet der henvises til tegningen, hvor

fig. 1 er en afbildning af en kendt type møllehat på en vindmølle,

fig. 2 er en afbildning af en udførelsesform for en møllehat på en vindmølle med en generator ifølge opfindelsen,

fig. 3 er en detailafbildning af en generator ifølge opfindelsen set vinkelret på en akse for generatoren,

fig. 4 er en yderligere detailafbildning af en generator ifølge opfindelsen,

fig. 5 er en detailafbildning af en generator ifølge opfindelsen set parallelt med en akse for generatoren,

fig. 6 er en anden detailafbildning af en generator ifølge opfindelsen, og

fig. 7 er en afbildning af et udførelsesform for et statormodul ifølge opfindelsen.

Generatoren er i den udførelse, der vises i figurerne, med 120 poler i 24 statormoduler. Generatoren er permanent magnetiseret. Andre udførelser, herunder med såvel børsteløs som slæberingsmagnetisering af en viklet rotor, vil også være egnede. Det kan her være relevant at udføre en viklet rotor, så også rotoren har moduler. En sådan særlig udførelse beskrives ikke nøjere her.

Figur 1 viser en kendt vindmølle i normal udførelse, med gear og standardgenerator. Rotorens vinger 1 er monteret på møllenavet 2, der er fastgjort til hovedakslen 3. Hovedakslen bæres af et hovedleje 4 forrest og af gearet 5 bagest. Med en elastisk kobling 6 er gearet forbundet til generatoren 7.

Figur 2 viser en vindmølle udført jævnfør opfindelsen. Hovedakslen 8 er båret af et forreste hovedleje 9 og et bageste hovedleje 10. Hovedakslen har bagest en klembøsning 11 som flange. Generatoren 12 har en aksel 13, som er båret af hovedakslens flange 11.

Figur 3 viser et længdesnit af generatoren i forstørrelse. Generatorakslen 14 bærer rotorens struktur 15, som på sin periferi har rotorblikket 16 og de permanente

magneter 17. Statorhuset 18 er båret af generatorlejerne 19 og har på sin periferi statormodulerne 20.

Figur 4 viser et længdesnit af statoren i større forstørrelse. Statorhuset 21 er ved en boltesamling (ikke vist) forbundet til statormodulet 22. Statormodulet har en kapsling 23 omkring statorblikket 24 og statorviklingen 25. I den viste udgave er generatoren udført med et statorhus, der har en ydre diameter d, som er præcis den samme som en yderdiameter som rotoren. Statormodulet er monteret således at statormodulet danner en indre diameter D, der er større end den ydre diameter d af rotoren og af statorhuset. En luftspalte A kan let justeres f.eks. ved hjælp af justeringsmidler, i den viste udførelsesform ved hjælp af shims 26, i samlingen mellem statorhus og statormodul, og eventuelle dimensionsafvigelser i statormodulet kan derved kompenseres.

Figur 5 viser et tværsnit af statoren i udsnit. Den enkelte pol 27 har en vikling 28, og er beskyttet af kapslingen 29. Den enkelte rotorpol 30 har en permanent magnet 31. I rotorens struktur er udskåret mandehuller 32 til bekvem passage af generatoren.

Figur 6 viser den komplette generator set fra hovedakselsiden. Et af statormodulerne 33 er vist afmonteret. De øvrige statormoduler sidder på deres respektive plads på statorhuset 34. Mandehuller 35 sikrer mulighed for gennemgang uanset rotorens stilling. Beslag for drejningsmomentstøtter 36 er anbragt i samme antal som statormodulerne, hvorved generatorens stator kan fastgøres til lodret nedfiring af hvert enkelt modul.

Den elektriske forbindelse mellem statormodulerne og er ikke vist på figuren. Den kan f.eks. etableres på den måde, at der monteres én central klemkasse på statorhuset, og at der fra en klemkasse på hvert statormodul trækkes et isoleret trefaset kabel fra statormodulet til den centrale klemkasse. Alternativt kan etableres en forbindelsesform med tre faseringe, der anbringes koncentrisk om hovedakslen på den ene side af statorhuset under passende afdækning. Fra de tre faseringe trækkes isolerede trefasede kabler radialt til de enkelte statormodulers klemkasser, og på faseringene monteres

direkte hovedkablerne, der overfører effekten til frekvensomformeren eller direkte til nettet.

Uanset udførelsen af forbindelserne lokalt på generatoren vil det være bekvemt at udføre hovedkablerne fra generatoren med et vist slæk, som kan optage de forskydninger, der vil forekomme mellem hvert statormodul og en central klemkasse, hvis generatorens stator skal kunne drejes for udskiftning af et eller flere statormoduler. Slikket kan eventuelt reduceres til, at statoren kun kan drejes en halv omgang med eller mod uret afhængigt af på hvilken side af et lodret plan, at statormodulet befinder sig, som skal udskiftes.

Figur 7 viser et statormodul i tværsnit og endebillede. Polen 37 har sin vikling 38 og er beskyttet af en indkapsling 39. Det samlede modul 40 fremtræder helt indkapslet.

PATENTKRAV

1. Generator, fortrinsvis til en vindmølle og især af den art, der drives direkte af vindmøllens rotor uden gear monteret mellem rotoren og generatoren, k e n d e t e g n e t ved, at i det mindste generatorens stator er udført med mindst to moduler, som er kapslede og tætte, og at disse mindst to moduler kan monteres og afmonteres uafhængigt af hinanden et eller flere ad gangen.

2. Generator ifølge krav 1, k e n d e t e g n e t ved, at det enkelte statormodul individuelt er indeholdt i en indkapsling med en tæthed, som i det væsentlige svarer til den indkapsling og tæthed, der ønskes i den færdige generator.

3. Generator ifølge krav 1 eller 2, k e n d e t e g n e t ved, at det enkelte statormodul, når de er monteret i en stator, tilsammen danner en lukket ring af statormoduler, der har en diameter, som i det væsentlige ikke overstiger diameteren af generatorens luftspalte.

4. Generator ifølge krav 1, 2 eller 3, k e n d e t e g n e t ved, at det enkelte statormodul kan forskydes radialt på statorstrukturen med henblik på justering af luftspalten.

5. Generator ifølge et hvilket som helst af de foregående krav, k e n d e t e g n e t ved, at det magnetiske kredsløb i det enkelte statormodul helt eller i det væsentlige er tilvejebragt med jern, der har retningsbestemte magnetiske egenskaber.

6. Generator ifølge et hvilket som helst af de foregående krav, k e n d e t e g n e t ved, at generatoren er monteret på en aksel, og at statoren under montage- og reparationsarbejder kan drejes i forhold til vindmøllens hovedaksel, uden at dette kræver væsentlig demontage udover generatorens momentunderstøtning.

7. Generator ifølge et hvilket som helst af de foregående krav, k e n d e t e g n e t ved, at generatoren under montage- og reparationsarbejder kan drejes i forhold til akslen på

en sådan måde, at det enkelte statormodul i det væsentlige kan fires lodret ned til jord- eller havoverfladen.

8. Generator ifølge et hvilket som helst af de foregående krav, k e n d e t e g n e t ved, at statoren omfatter mellem 2 og 48 moduler, fortrinsvis 12 moduler, at hvert modul er indeholdt i en indkapsling, og at et givet antal sidestillede indkapslinger, der er i anlæg med hinanden, danner en lukket ring af statormoduler.

9. Generator ifølge krav 8, k e n d e t e g n e t ved, at de sidestillede indkapslinger har en indre flade, der vender indefter mod rotoren, og som danner den indre periferi for statoren, at den indre periferi af statoren er cirkulær, at rotoren har en ydre periferi, der ligeledes er cirkulær, og at luftspalten mellem den ydre periferi af rotoren og den indre periferi af statoren i det væsentlige har en konstant bredde på mellem 2 mm og 10 mm, fortrinsvis på 5 mm.

10. Generator ifølge ethvert af de foregående krav, k e n d e t e g n e t ved, at bredden af luftspalten mellem rotoren og statoren kan reguleres individuelt for hvert statormodul og uafhængigt af hinanden ved hjælp af dertil egnede reguleringsmidler, f.eks. shims, ved at en afstand reguleres mellem en ydre periferi af statorstrukturen og en indre periferi af et givet statormodul.

11. Statormodul til brug i generator ifølge ethvert af de foregående krav, hvilket statormodul omfatter i det mindste to poler og et antal viklinger omkring polerne, k e n d e t e g n e t ved, at statormodulet er bestemt til et udgøre en del af en hel stator, og at statormodulet er indeholdt i en indkapsling med tætning svarende til en given ønsket kapslingsgrad.

12. Anvendelse af en generator ifølge ethvert af de foregående krav i en vindmølle.

SAMMENDRAG

GENERATOR TIL EN VINDMØLLE, STATORMODUL TIL BRUG I EN SÅDAN GENERATOR SAMT ANVENDELSE AF EN SÅDAN GENERATOR .

Opfindelsen angår en generator til en vindmølle. Generatoren er af den type, der er direkte koblet til hovedakslen for vindrotoren på vindmøllen. Generatoren har en stator, der består af et antal statormoduler, der er individuelle og som kan monteres, repareres og afmonteres individuelt og uafhængigt af hinanden. Det medfører at det er meget nemt og dermed billigere at montere møllen, specielt til havs, idet statoren til generatoren kan transporteres i mindre enheder, hvilket også gør det nemmere at samle statoren i møllehatten. Ved efterfølgende reparationer og anden vedligeholdelse af generatoren er det heller ikke nødvendigt at anvende store kraner, men tilstrækkeligt at anvende mindre hejseanordninger, der kan håndteres af en til to mand.

Fig. 6

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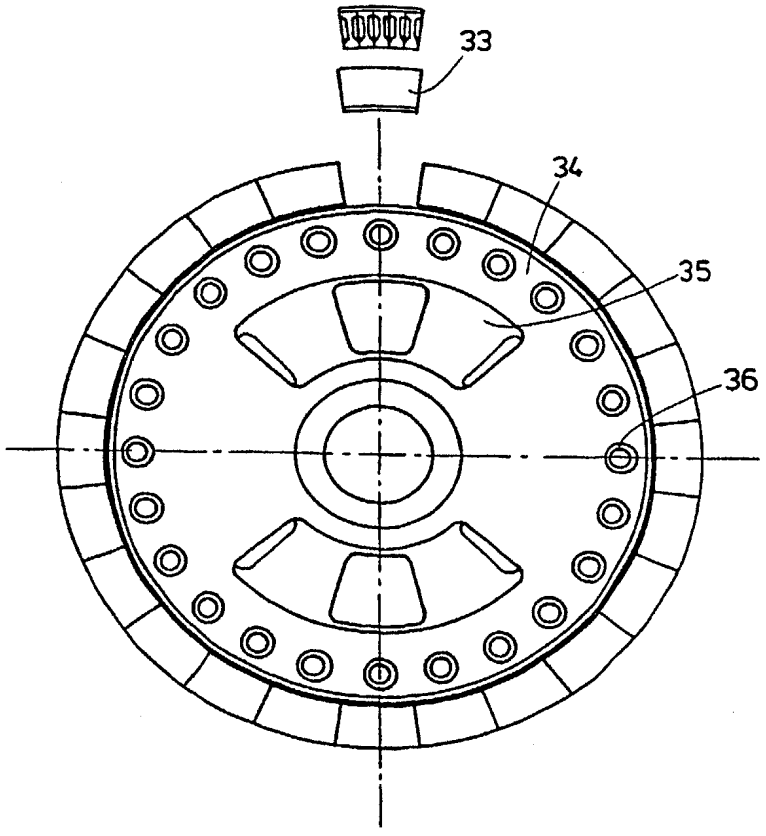
(54) Title: GENERATOR FOR A WINDMILL, STATOR MODULE FOR USE IN SUCH A GENERATOR AND USE OF SUCH A GENERATOR

(57) Abstract

The invention concerns a generator for a windmill. The generator is of the kind being directly coupled to the main shaft of the wind rotor of the windmill. The generator is a stator consisting of a number of stator modules that are individual and which may be installed, repaired and dismantled individually and independently of each other. This implies that it is very easy and thereby cheaper to mount the mill, especially at sea, as the stator for the generator can be transported in smaller units, which also makes it easier to assemble the stator in the tower top section. By subsequent repairs and other maintenance of the generator it is not necessary either to use large cranes, but it is sufficient to use smaller hoisting devices that may be handled by one or two persons.



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GENERATOR FOR A WINDMILL, STATOR MODULE FOR USE IN SUCH A GENERATOR AND USE OF SUCH A GENERATOR

Background of the invention

The present invention concerns to a generator for a windmill of the kind driven directly by the rotor of the windmill without any gearbox installed between the rotor and the generator. The invention also concerns a stator module for such a generator and a use of such a generator in a windmill.

It is known that it is necessary to insert a speed increasing gearbox between the rotor and the generator of a windmill. The rotational speed is of the magnitude 20 rpm for large windmills while a normal 4-pole generator has a synchronous speed of rotation of 1500 rpm. A suitable speed increasing gearbox will thus have a gear ratio of 1:75.

It is known that the speed increasing main gearbox of a windmill constitutes a substantial part of the cost price, and besides that it is a relatively vulnerable main component. In many cases, by possible damages, it will be necessary to dismantle the gearbox for repair. In consideration of the gearbox for a windmill in the 2 MW class having a weight of up to 15 tons and being mounted in a machine disposed on a tower with a height of 60-100 m it is obvious that such a replacement may be very costly.

The risk of incurring considerable expenses by a possible replacement is multiplied if large windmills are erected at sea. Handling of weights of 15 tons or more in 60-100 m height may only be performed with very large float cranes or very large mobile cranes placed on large barges. Working with this kind of equipment at the open sea can only be done under good weather conditions. Therefore, there may be periods of several months during the winter where it is not possible to replace a damaged gearbox.

The generator itself is also a heavy main component, typically with a weight of 5 tons by 2 MW rated output. As with the gearbox it cannot be avoided that there will be a

certain risk of breakdown of the generator. The conditions by replacing this are just as adverse as for the gearbox.

It is also known that there are gearless transmission systems for windmills where gearbox and generator are substituted by a slowly turning, multipolar generator. Such a directly driven generator can be made as a synchronous generator with winded rotor or with permanent magnets, or it can be designed as alternative types of generators. Common to directly driven, multipolar generators is that their dimensions are great. The air gap diameter by 2 MW rated output may e.g. be of the magnitude 5 m by an embodiment with winded rotor, and a little less by an embodiment with permanently magnetised rotor.

By a directly driven, multipolar generator, the gearbox becomes superfluous. Usually, it will be necessary to insert a frequency converter between the generator and the network since it is difficult to achieve a pole number corresponding to the 50 Hz mains frequency by nominal rpm. Hence multipolar generators normally generate alternating current with a somewhat lower frequency, e.g. 20 Hz, whereby the number of poles may be reduced to 2/5, and more space for the coil windings is provided. Even though the frequency converter constitutes increased complexity in relation to a generator system where the generator is coupled directly to the network, it may be appreciated that the reduction in complexity by elimination of the main gearbox more than offsets this.

A substantial drawback by a directly driven, multipolar generator are the physical dimensions. By an air gap diameter of 5 m, the outer diameter becomes in the magnitude of 6 m, and the dead load becomes about the dead load the replaced components, gearbox and normal generator, i.e. 20 tons or more. The large outer diameter makes transport difficult, and the dead load does not reduce the problem with replacement for repair by possible breakdowns.

A further difficulty arises in the normal configurations with multipolar generators where the generator is placed between the rotor and the tower in order to yield a com-

pact machine construction. In addition, here it will be necessary to dismantle the whole rotor by eventual dismantling of the generator.

There is known an embodiment of a directly driven generator, US patent 5,844,341, where the stator of the generator is made with modules which largely constitute individual polar pairs and which are disposed on support arms outside the poles. The advantage of this construction is that a damaged part of the generator may be replaced without taking down the whole generator. The drawback by this configuration is, however, that the electromechanical properties in this form of modular construction with single polar pairs separated by air gaps may be disadvantageous, and that possible dismantling of a single stator module can involve that the whole generator has to be opened in situ implying risk of humidity, dirt etc.. and that it may be cumbersome if the stator module has to be taken out in a disadvantageous direction.

Another design of a directly driven generator is known, US patent 4,866,321, where an axial generator has a stator designed with modules each containing a single pole winded around a coil and installed in an arrangement where the coil may be drawn radially out from the stator. The advantage of this construction is, as with the previous, that a damaged pole in the generator may be replaced without the whole generator to be taken down. As a consequence of the mechanical construction it is likely that the electromechanical properties will be better than in the above arrangement. The drawback is, however, that possible dismantling of a single stator module can involve that the whole generator has to be opened in situ implying risk of humidity, dirt etc., and that it may be cumbersome if the stator module has to be taken out in a disadvantageous direction.

It is the purpose of the present invention to provide a generator of the kind described above, preferably a directly driven, multipolar generator in a windmill, and where the drawbacks connected with known generators are relieved as the stator of the generator is more easy to install and to repair.

This purpose is achieved according to the present invention with a generator which is peculiar in that at least the stator of the generator is made with at least two modules which are fully enclosed and tight, and that these at least two modules may be mounted and dismantled independently of each other one or more at a time. Each of the least two modules contains at least two pairs of poles.

By designing the generator according to the invention a number of advantages are attained as compared with the prior art.

The advantages of a directly driven, multipolar generator as compared with more conventional transmission systems with gearbox and standard generator are maintained in a generator according to the invention.

By designing the electrically active part of the generator stator as modules, each having the necessary degree of sealing (typically there is desired sealing corresponding to IP54), the structural part of the stator housing may be designed with an outer diameter of a magnitude as the air gap diameter. Hereby the outer diameter of the part of the stator normally being installed when transporting the windmill to the erection site is reduced to the minimum determined by the air gap. Concerning the transport, there is a substantial advantage in having the least possible outer diameter. The winding modules of the stator then have to be retrofitted at the erection site.

By making the winding as modules, the space requirements and the complexity in the winding are reduced considerably. The stator modules may be performed in serial production, and the single modules may be finished with sealing, terminal box etc. under convenient conditions. Therefore, the risk becomes much less for winding damages caused by handling under difficult access conditions in a large construction.

A special embodiment of a stator module according to the invention is characterised in that the stator module is intended for constituting a part of a complete stator, and that the stator module is contained in an enclosure with tightness corresponding to a given desired degree of enclosure.

By making the stator modules with the necessary tightness so that they may be installed and dismantled in situ there is achieved a very essential advantage by possible damages. Damages on a generator winding arise normally by an initial flashover at one locality, e.g. due to accidental isolation damages, humidity or the like. Because of the great amounts of energy released by a burning off, the damage, however, typically causes more general effects on the whole winding in a standard generator. Large parts of the winding may be damaged by melting, by other thermal effects and by sooting up. In the modular construction generator, however, the damage is usually limited just to the module in which the initial flashover occurred. Thus it is not necessary that the whole winding is dismantled as the repair may be limited to the module(s) concerned.

The segmented construction of the generator gives the possibility of utilising particularly advantageous material properties normally not available by rotating electric machines. The fact is that iron can be made with directional magnetic properties. This kind of field oriented iron is used in transformers and is therefore normally denoted transformer sheet metal. On a normal rotating machine where sheet metal for stator and rotor is punched in one piece, transformer sheet metal cannot be used as the magnet field lines will have every direction about the rotor axis. The advantage of the good magnetic properties in the most advantageous field direction is therefore more than offset by corresponding bad magnetic properties perpendicular to the most advantageous field direction. Therefore, on rotating machines so-called motor sheet metal is used, which does not have directional magnetic properties. The iron losses are therefore somewhat greater in rotating machines than in transformers with corresponding variations in flux.

On the segmented generator, however, the situation is otherwise than on normal rotating machines. By making the generator with six or more stator modules it may be achieved that the magnet field lines within each segment will not deviate much more than 10 degrees from the most advantageous direction in the iron. The use of transformer sheet metal therefore becomes relevant. and thereby there is achieved possibility of a considerable reduction of the magnetising losses as compared with the losses when using generator sheet metal. Furthermore, a better magnetic conductivity is

achieved, whereby higher induction and field strength in the air gap is achieved with consequently greater magnetic power and torque.

By the handling itself essential advantages are also achieved. Each single module will have a weight much less than the complete generator, and also much less than the weight of a normal gearbox or a normal generator. By a directly driven, multipolar generator with a weight of 20 tons, the modules may conveniently be made in a number so that each has a weight of 500 kg. By a weight of this magnitude the modules may be replaced singularly by a few fitters by means of a small crane which advantageously may be built into the cabin of a windmill.

The advantage compared with prior art is especially of importance where large windmills are erected at sea. The very large floating cranes or very large mobile cranes on large barges necessary for repair works on known transmissions systems, whether these are conventional with gearbox and standard generator, or with directly driven, multipolar generator, may be completely avoided. The only condition for repair is that it is possible to get service personnel on the mill. Replaced generator modules may be lowered by a small built-in crane, and they may be sailed to and from the windmill on a normal service boat. A number of generator modules may even be stored in the mill top as spare parts, whereby lowering and sea transport may be postponed until periods with favourable weather conditions.

By making the generator in a shaft mounted version where the torque is absorbed at some specific points by moment supports, there may be achieved the advantage that the stator of the generator may be turned to the most optimal position by repair works. Installing and dismantling modules may therefore occur at one definite position irrespectively of where each module is disposed on the generator when the generator is in its normal operative position. For example, the stator of the generator may be turned so that the module to be replaced turns downward and therefore may immediately be lowered through a hatch at the bottom of the windmill cabin.

Description of the drawing

The invention is described more closely in the following as reference is made to the drawing, where:

Fig. 1 is an illustration of a prior art kind of tower top section of a windmill,

Fig. 2 is an illustration of an embodiment of a tower top section of a windmill with a generator according to the invention,

Fig. 3 is a detailed illustration of a generator according to the invention as seen perpendicularly to an axis of the generator,

Fig. 4 is a further detailed illustration of a generator according to the invention,

Fig. 5 is a detailed illustration of a generator according to the invention viewed in parallel with an axis of the generator,

Fig. 6 is a second detailed illustration of a generator according to the invention, and

Fig. 7 is an illustration of an embodiment of a stator module according to the invention.

In the design shown in the figures, the generator is with 120 poles in 24 stator modules. The generator is permanently magnetised. Other embodiments, including such with brushless as well as slipring magnetisation of a winded rotor, are also suitable. Here it may be relevant to design a winded rotor so that the rotor also has modules. Such a special embodiment is not described any further here.

Fig. 1 shows a prior art windmill in normal design with gearbox and standard generator. The wings 1 of the rotor are mounted on the mill hub 2 which is fastened to the main shaft 3. The main shaft is supported by a main bearing 4 at the front and by the gearbox 5 at the rear. The gearbox is connected to the generator 7 with an elastic coupling 6.

Fig. 2 shows a windmill designed according to the invention. The main shaft 8 is supported by a front main bearing 9 and a rear main bearing 10. The main bearing has a split bushing 11 as flange at the rear. The generator 12 has a shaft 13 which is supported by the flange 11 of the main shaft.

Fig. 3 shows an enlarged longitudinal section of the generator. The generator shaft 14 supports the structure 15 of the rotor which at its periphery has the rotor sheet metal 16 and the permanent magnets 17. The stator housing 18 is supported by the generator bearings 19 and has the stator modules 20 at its periphery.

Fig. 4 shows more enlarged a longitudinal section of the stator. The stator housing 21 is connected to the stator module 22 by a screw bolt connection (not shown). The stator module has an enclosure 23 around the stator sheet metal 24 and the stator winding 25. In the shown version, the generator is made with a stator housing having an outer diameter d which is exactly the same as an outer diameter of the rotor. The stator module is thus installed so that the stator module forms an inner diameter D which is greater than the outer diameter d of the rotor and of the rotor housing. An air gap A may easily be adjusted, e.g. by means of adjusting means, in the embodiment shown by means of shims 26, at the joint between stator housing and stator module, and possible dimensional deviations in the stator module may thereby be compensated for.

Fig. 5 shows in part a cross-section of the stator. The single pole 27 has a winding 28 and is protected by the enclosure 29. The single rotor pole 30 has a permanent magnet 31. In the rotor structure, manholes 32 are cut out for convenient passage of the generator.

Fig. 6 shows the complete generator as seen from the main shaft side. One of the stator modules 33 is shown dismantled. The other stator modules are at their respective places on the stator housing 24. Manholes 35 ensure the possibility of going through irrespectively of the position of the rotor. Fittings for torque supports 36 are provided with the same number as the stator modules whereby the stator of the generator may be fastened for vertical lowering of each single module.

The electric connection between the stator modules and is not shown on the Figure. It may e.g. be established in the way that there is mounted one central terminal box on the stator housing, and that from a terminal box on each stator module there is drawn an isolated three-phase cable from the stator module to the central terminal box. Alter-

natively, there may be established a connection form with three phase rings provided concentrically about the main shaft at one side of the stator housing under suitable covering. Isolated three-phase cables are drawn radially from the three phase rings to the terminal boxes of each of the stator modules, and the main cables transmitting the power to the frequency converter or directly to the network are installed directly on the phase rings.

Irrespectively of the local connections on the generator, it will be convenient to make the main cables from the generator with a certain slack that may absorb the displacements occurring between each stator module and a central terminal box if the stator of the generator is to be turned for each replacement of one or more stator modules. The slack may possibly be reduced for the stator to be capable of being turned only a half turn clockwise or counterclockwise depending on which side of a vertical plane the stator module to be replaced is situated.

Fig. 7 shows a stator module in cross-section and as end view. The pole 37 has its winding 38 and is protected by an enclosure 39. The assembled module 40 appears completely enclosed.

CLAIMS

1. Generator, preferably for a windmill and especially of the kind driven directly by the rotor of the windmill without any gearbox installed between the rotor and the generator, characterised in that at least the stator of the generator is made with at least two modules which are fully enclosed and tight, and that these at least two modules may be mounted and dismantled independently of each other one or more at the time.

2. Generator according to claim 1, characterised in that each single stator module are individually contained in an enclosure with a tightness substantially corresponding to the enclosing and tightness that is desired in the finished generator.

3. Generator according to claim 1 or 2, characterised in that each single stator module, when they are installed in a stator, together form a closed ring of stator modules having a diameter which does not substantially exceed the diameter of the air gap of the generator.

4. Generator according to claim 1, 2 or 3, characterised in that each single stator module may be displaced radially on the stator structure with the purpose of adjusting the air gap.

5. Generator according to any preceding claim, characterised in that the magnetic circuit in each single stator module is completely or substantially provided by iron having directional magnetic properties.

6. Generator according to any preceding claim, characterised in that the generator is mounted on a shaft, and the stator during mounting and repair work may be turned in relation to the main shaft of the windmill without this requiring substantial dismantling besides the moment support of the generator.

7. Generator according to any preceding claim, characterised in that the generator during mounting and repair works may be turned in relation to the shaft in such a way that each single stator module essentially may be lowered vertically to the ground or sea surface.

8. Generator according to any preceding claim, characterised in that the stator comprises between 2 and 48 modules, preferably 12 modules, that each module is contained in an enclosure, and that a given number of juxtaposed enclosures abutting on each other form a closed ring of stator modules.

9. Generator according to claim 8, characterised in that the juxtaposed enclosures have an inner surface facing inward toward the rotor and forming the inner periphery for the stator, that the inner periphery of the stator is circular, that the rotor has an outer periphery which is also circular, and that the air gap between the outer periphery of the rotor and the inner periphery of the stator substantially have a constant width between 2 mm and 10 mm, preferably 5 mm.

10. Generator according to any preceding claim, characterised in that the width of the air gap between the rotor and the stator may be adjusted individually for each stator module and independently of each other by means of suitable adjusting means, e.g. shims, by adjusting a distance between an outer periphery of the stator structure and an inner periphery of a given stator module.

11. Stator module for use in a generator according to any preceding claim, which stator module comprises at least two poles and a number of windings around the poles, characterised in that the stator module is intended for constituting a part of a complete stator, and that the stator module is contained in an enclosure with tightness corresponding to a given desired degree of enclosure.

12. Use of a generator according to any preceding claim in a windmill.

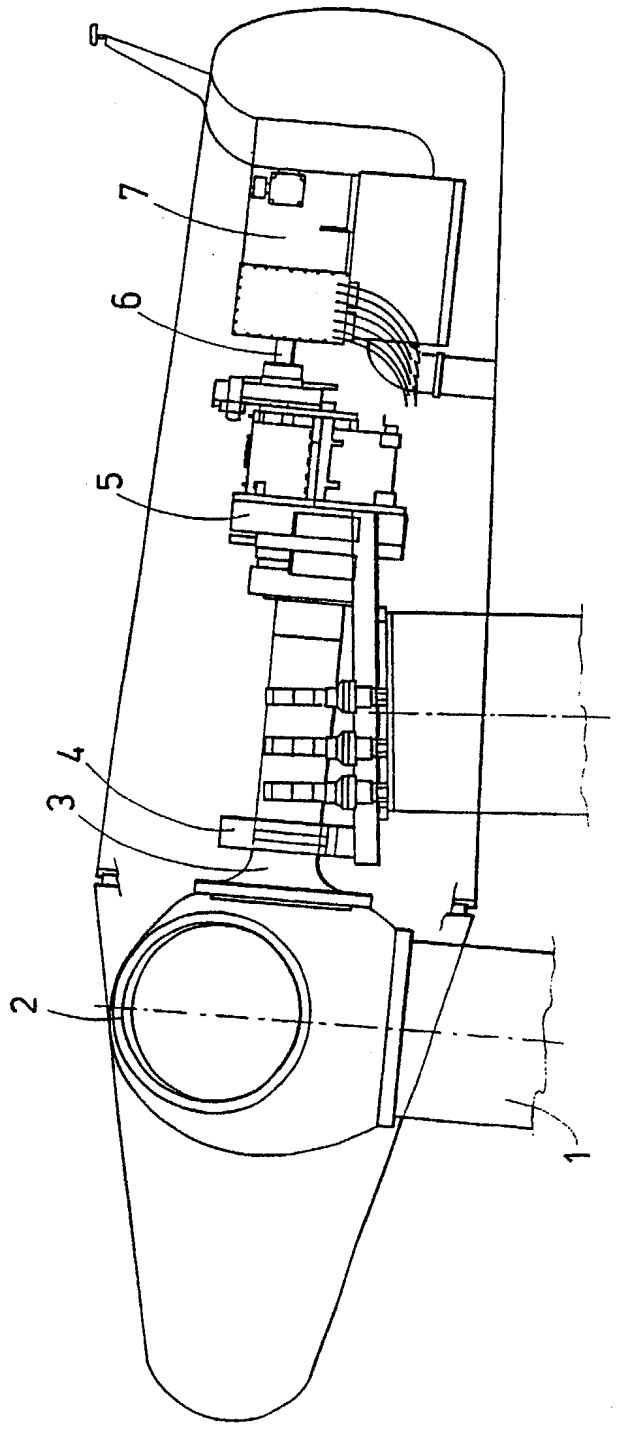

Fig.1

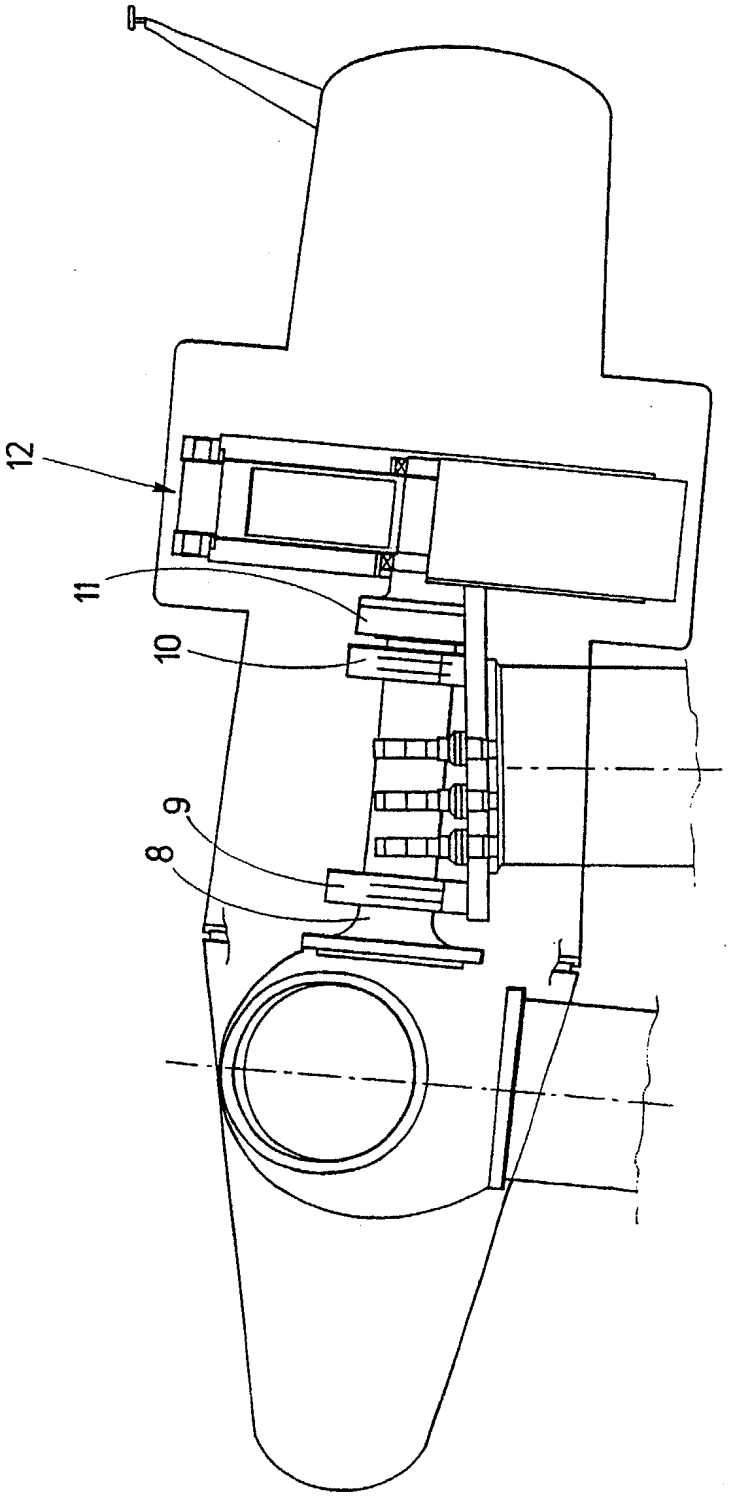

Fig.2

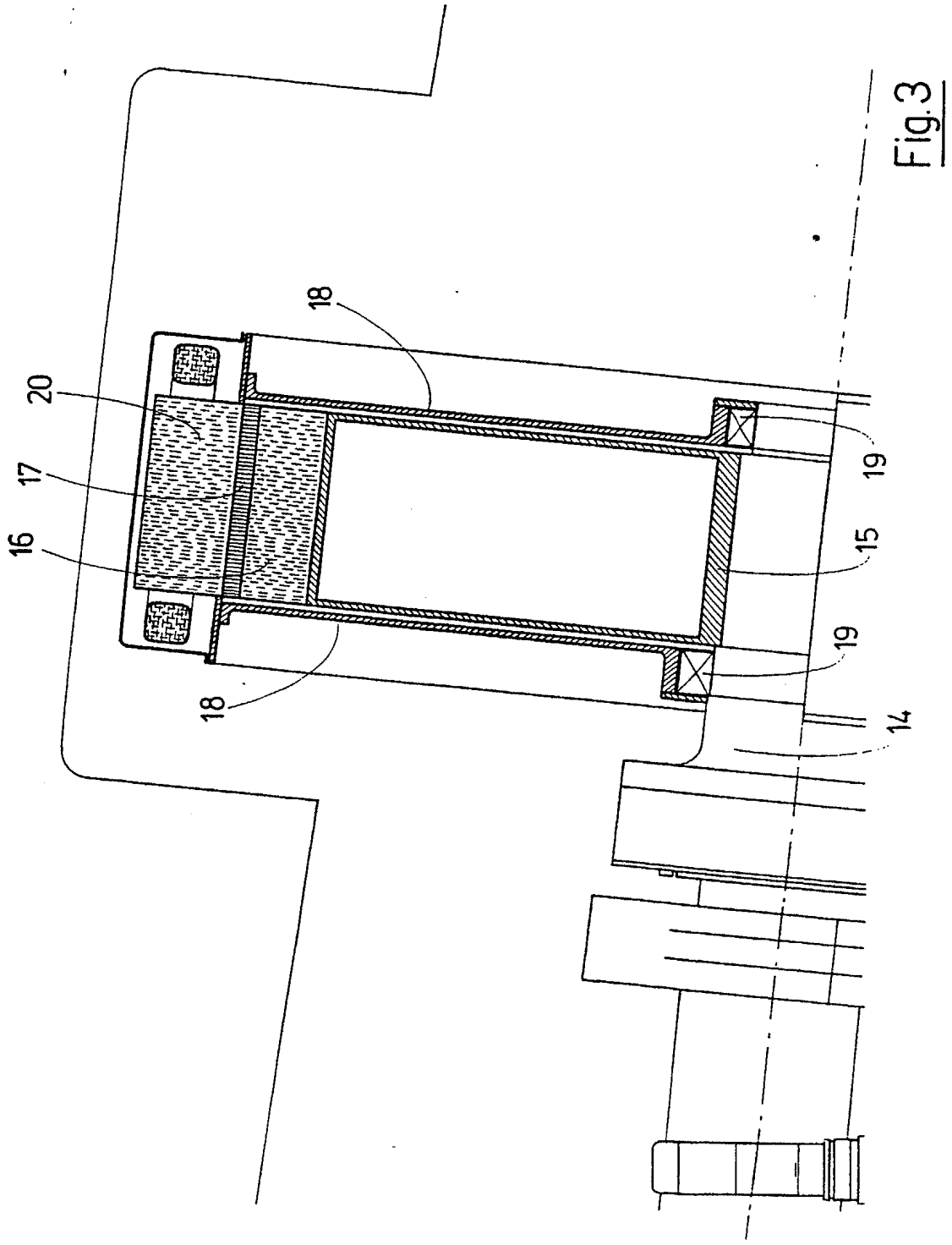

Fig.3

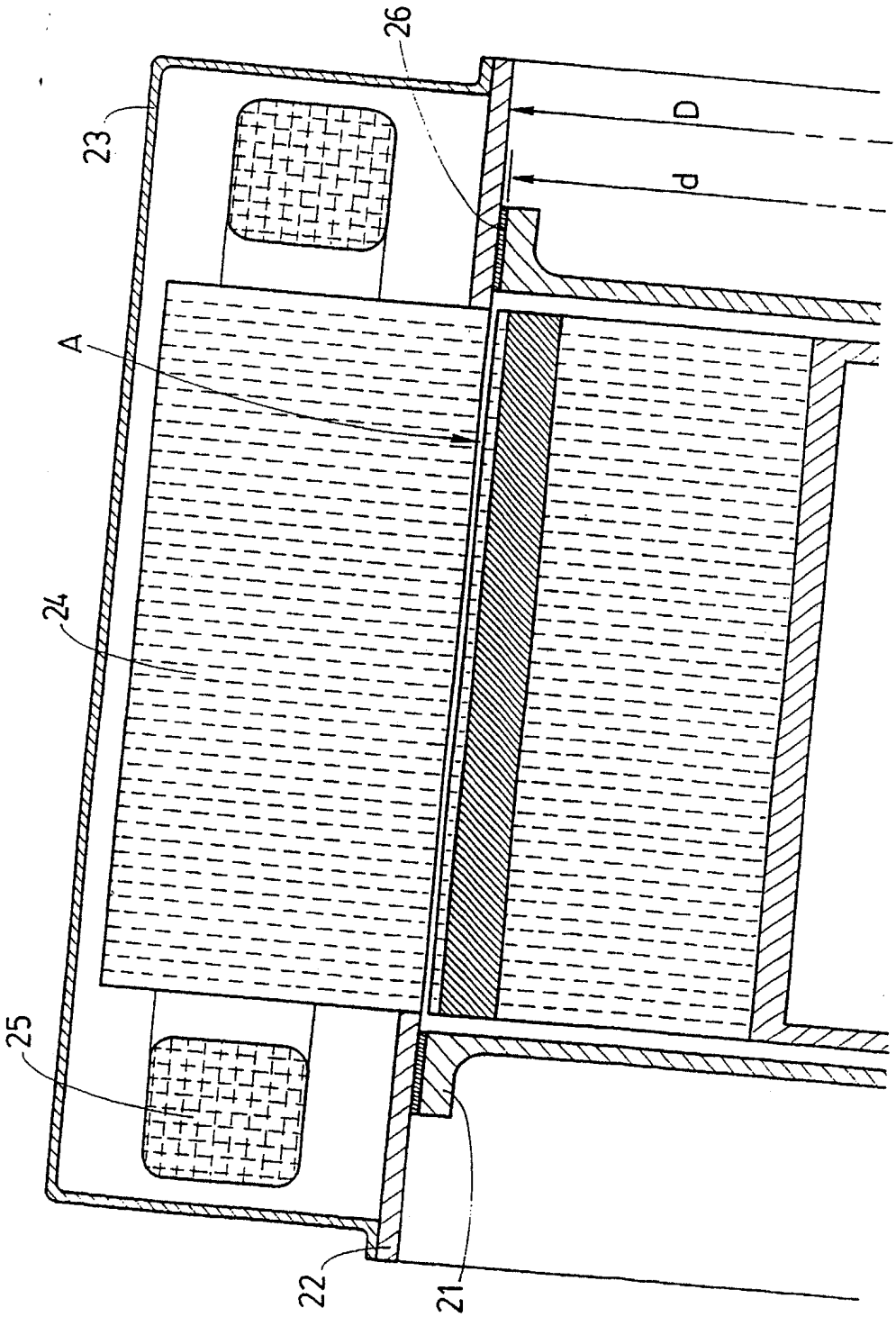

Fig.4

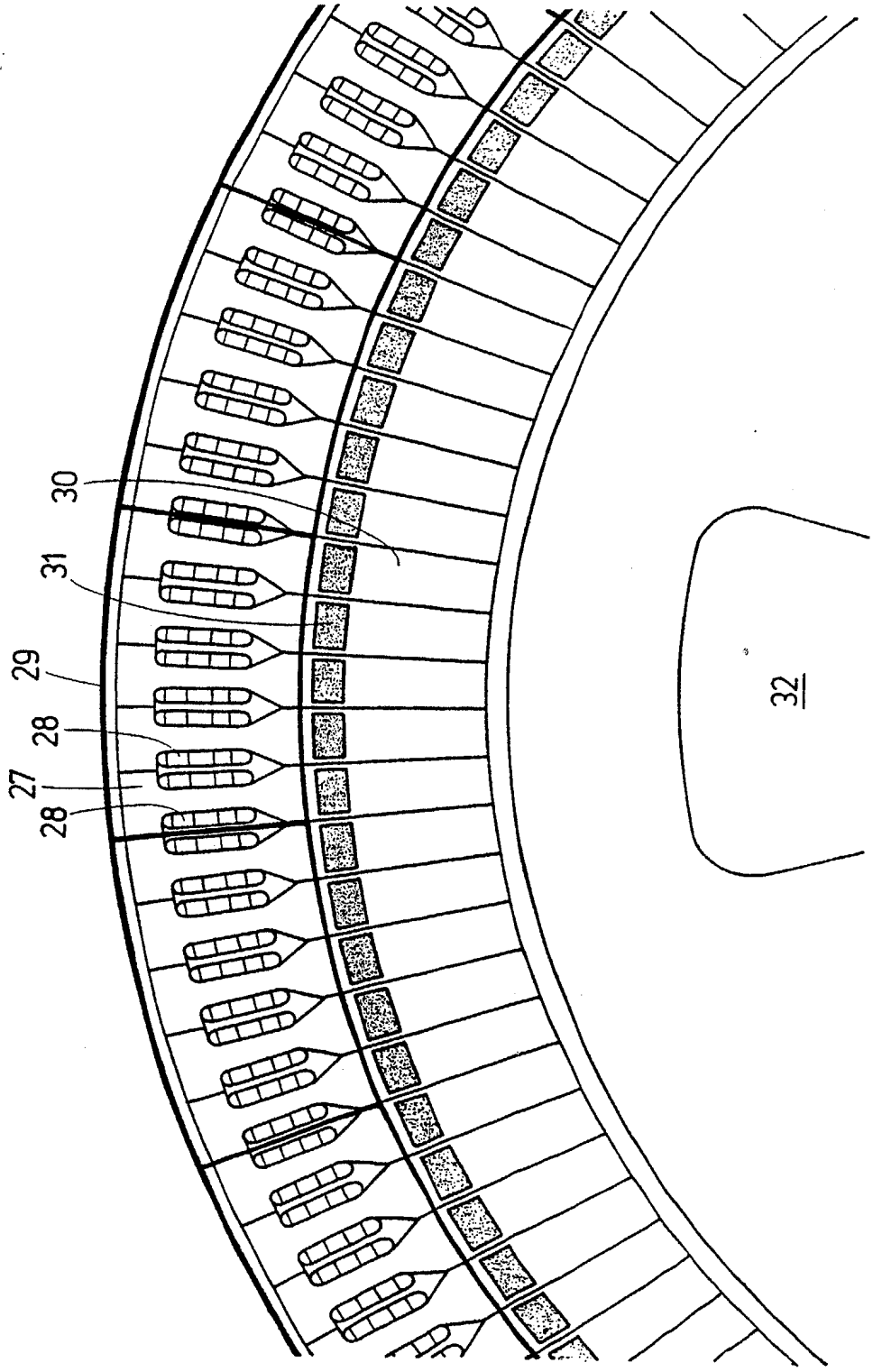

Fig.5

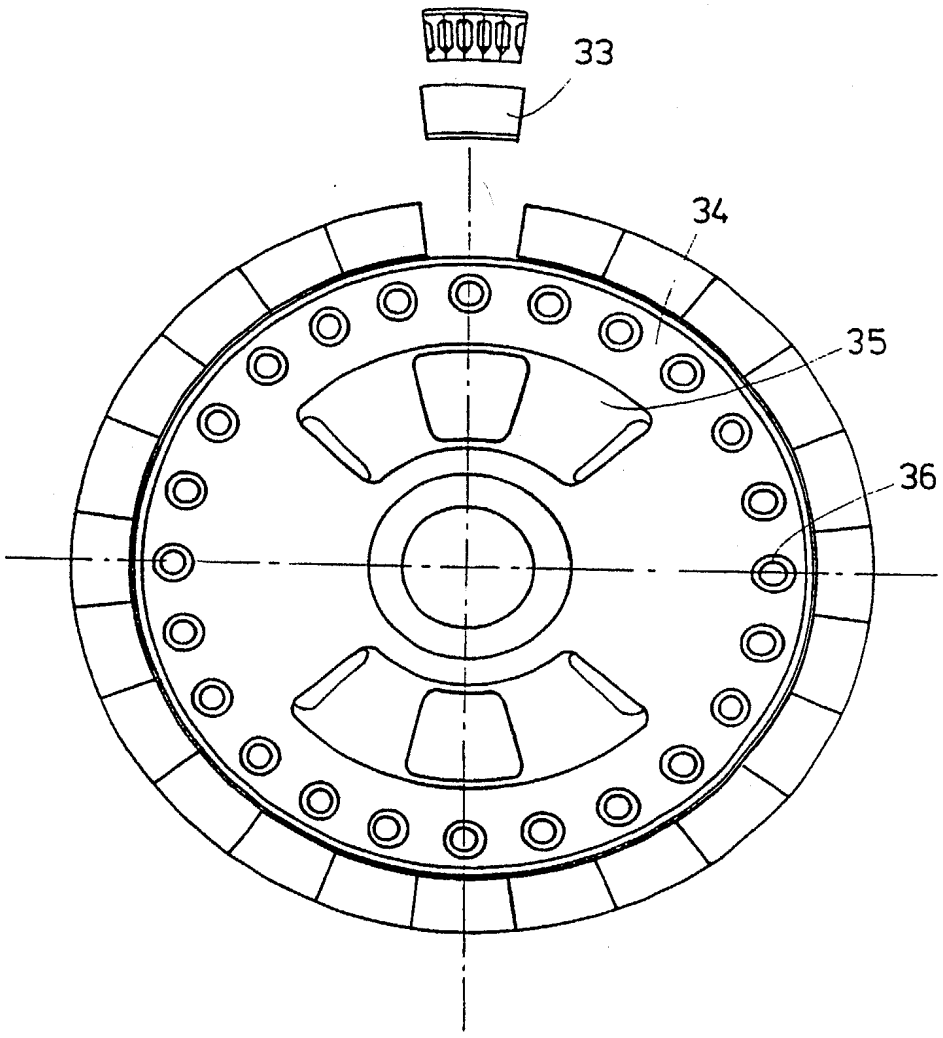

Fig.6

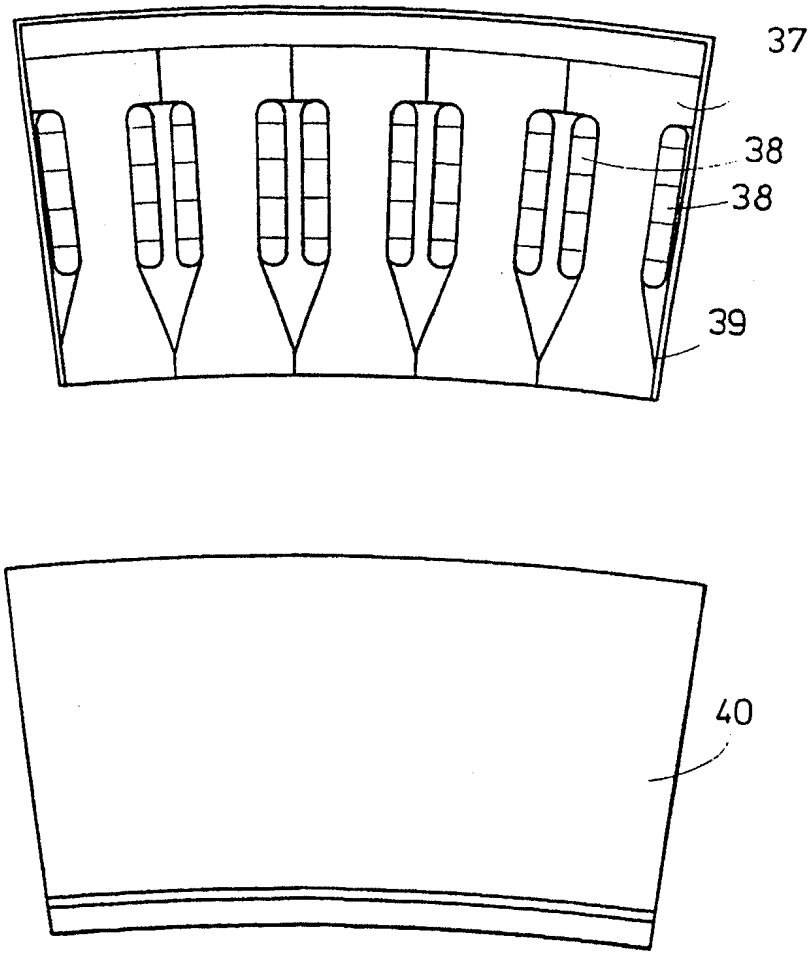

Fig.7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 00/00162

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: H02K 1/12, H02K 15/02
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4866321 A (HUBERT J. BLANCHARD ET AL), 12 Sept 1989 (12.09.89), column 1, line 57 - column 2, line 18; column 3, line 65 - line 66; column 4, line 8 - line 29 --	1-3,5-9, 11-12
X	US 5844341 A (EDWARD SPOONER ET AL), 1 December 1998 (01.12.98), column 4, line 16 - line 52; column 5, line 55 - line 58, figures 2,3, abstract --	1,3,8,9

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" erlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 August 2000	29 -08- 2000
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Håkan Sandh/MN Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/DK 00/00162

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO A9109446 (LENGD ELEKTROSILA) 1991-06-27 (abstract) World Patents Index (online) London, U.K.: Derwent Publications, Ltd. (retrieved on 2000-08-18) Retrieved from EPO WPI Database DW 199128 Accession No. 1991-208366 see abstract ---	1,3,8
X	WO 9820595 A1 (ASEA BROWN BOVERI AB), 14 May 1998 (14.05.98), page 15, line 28 - page 16, line 29, figure 4, abstract --- --------	1,3,8

INTERNATIONAL SEARCH REPORT

Information on patent family members

08/05/00

International application No.
PCT/DK 00/00162

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		DK 627805 T	20/01/97
		EP 0627805 A,B	07/12/94
		SE 0627805 T3	
		ES 2095718 T	16/02/97
		GB 2278738 A,B	07/12/94
		GB 9410259 D	00/00/00
		JP 7075311 A	17/03/95
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		EP 0935837 A	18/08/99
		SE 9604026 A	05/05/98
		SE 9703718 A	14/04/99